FINAL INTERIM FEASIBILITY STUDY REPORT

SAN JACINTO RIVER WASTE PITS SUPERFUND SITE

May 2016

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1

1 INTRODUCTION 1

1.1 Purpose and Organization of the Report 1

1.2 Regulatory Background 2

2 SETTING 3

2.1 Location and History 3

2.2 Land Use 4

2.2.1 Recreational and Navigational Use 4

2.3 Biological Habitat 5

2.4 Physical Description 6

2.4.1 Waterway Hydrodynamics 6

2.4.2 Riverbed Characteristics and Sediment Transport 8

2.5 Nature and Extent of COCs 9

2.5.1 North of I-10 10

2.5.2 Area of Investigation South of I-10 10

2.5.3 Prior Actions at the SJRWP Site 11

2.5.3.1 Effectiveness of the Time Critical Removal Action 15

2.5.4 Sources of COCs 16

2.5.5 Chemical Fate and Transport 17

2.5.5.1 Bioaccumulation 18

2.5.6 Fate and Transport Modeling 19

3 BASIS FOR REMEDIAL ACTION 21

3.1 Recommended Protective Concentration Levels 21

3.2 Remedial Action Objectives 23

3.3 Applicable or Relevant and Appropriate Requirements 25

3.3.1 Water Quality and Water Resources 27

3.3.1.1 Section 303 and 304 of the Clean Water Act and Texas Surface Water Quality Standards 27

3.3.1.2 Section 401 Water Quality Certification of the Clean Water Act as Administered by Texas 29

3.3.1.3 Section 404 and 404 (b)(1) of the Clean Water Act 29
3.3.1.4 Texas Pollutant Discharge Elimination System 30
3.3.1.5 Rivers and Harbor Act and Texas State Code Obstructions to Navigation . 31
3.3.2 Protected Species Requirements..31
3.3.3 Coastal Zone Management Act and Texas Coastal Management Plan..................32
3.3.4 Floodplain 32
3.3.5 Cultural Resources Management..33
3.3.6 Noise Control Act 33
3.3.7 Hazardous Materials Transportation and Waste Management 33

4 DEVELOPMENT OF REMEDIAL ALTERNATIVES 34

4.1 Remedial Technologies Screening..34
4.1.1 Institutional Controls 34
4.1.2 Monitored Natural Recovery 37
4.1.3 Treatment...37
4.1.4 Containment 38
4.1.5 Removal 40
4.1.6 Disposal 42
4.2 Assembly of Remedial Alternatives 43
4.3 Remedial Alternatives for the Area North of I-10 46
4.3.1 Alternative 1N – Armored Cap and Ongoing OMM (No Further Action)...........46
4.3.2 Alternative 2N – Armored Cap, Institutional Controls and Monitored Natural Recovery 47
4.3.3 Alternative 3N – Permanent Cap, Institutional Controls and Monitored Natural Recovery 48
4.3.4 Alternative 4N – Partial Solidification/Stabilization, Permanent Cap, Institutional Controls and Monitored Natural Recovery..50
4.3.5 Alternative 5N – Partial Removal, Permanent Cap, Institutional Controls and Monitored Natural Recovery...52
4.3.6 Alternative 5aN – Partial Removal of Materials Exceeding the PRG, Permanent Cap, Institutional Controls and Monitored Natural Recovery 53
4.3.7 Alternative 6N – Full Removal of Materials Exceeding the PRG, Institutional Controls and Monitored Natural Recovery 55
4.4 Remedial Alternatives for the Area South of I-10 56

4.4.1 Alternative 1S – No Further Action 56
4.4.2 Alternative 2S – Institutional Controls 56
4.4.3 Alternative 3S – Enhanced Institutional Controls 57
4.4.4 Alternative 4S – Removal and Off-site Disposal....58

5 DETAILED ANALYSIS OF REMEDIAL ALTERNATIVES 60

5.1 Area North of I-10....62
5.1.1 Alternative 1N – Armored Cap and Ongoing OMM (No Further Action)....62
5.1.1.1 Overall Protection of Human Health and the Environment 62
5.1.1.2 Compliance with ARARs 62
5.1.1.3 Long-Term Effectiveness 63
5.1.1.4 Reduction of Toxicity, Mobility or Volume 64
5.1.1.5 Short-Term Effectiveness.... 64
5.1.1.6 Implementability 64
5.1.1.7 Cost.... 64
5.1.2 Alternative 2N – Armored Cap, Institutional Controls and Monitored Natural Recovery 65
5.1.2.1 Overall Protection of Human Health and the Environment 65
5.1.2.2 Compliance with ARARs 66
5.1.2.3 Long-Term Effectiveness 66
5.1.2.4 Reduction of Toxicity, Mobility or Volume 67
5.1.2.5 Short-Term Effectiveness.... 67
5.1.2.6 Implementability 67
5.1.2.7 Cost.... 68
5.1.3 Alternative 3N – Permanent Cap, Institutional Controls and Monitored Natural Recovery 68
5.1.3.1 Overall Protection of Human Health and the Environment 68
5.1.3.2 Compliance with ARARs 69
5.1.3.3 Long-Term Effectiveness 70
5.1.3.4 Reduction of Toxicity, Mobility or Volume 71
5.1.3.5 Short-Term Effectiveness.... 71
5.1.3.6 Implementability 72
5.1.3.7 Cost.... 72

5.1.4 Alternative 4N – Partial Solidification/Stabilization, Permanent Cap, Institutional Controls and Monitored Natural Recovery....73
5.1.4.1 Overall Protection of Human Health and the Environment.... 73
5.1.4.2 Compliance with ARARs.... 74
5.1.4.3 Long-Term Effectiveness.... 75
5.1.4.4 Reduction of Toxicity, Mobility or Volume.... 76
5.1.4.5 Short-Term Effectiveness.... 76
5.1.4.6 Implementability.... 78
5.1.4.7 Cost.... 79
5.1.5 Alternative 5N – Partial Removal, Permanent Cap, Institutional Controls and Monitored Natural Recovery....79
5.1.5.1 Overall Protection of Human Health and the Environment.... 79
5.1.5.2 Compliance with ARARs.... 80
5.1.5.3 Long-Term Effectiveness.... 81
5.1.5.4 Reduction of Toxicity, Mobility or Volume.... 82
5.1.5.5 Short-Term Effectiveness.... 82
5.1.5.6 Implementability.... 84
5.1.5.7 Cost.... 84
5.1.6 Alternative 5aN – Partial Removal of Materials Exceeding the PRG, Permanent Cap, Institutional Controls and Monitored Natural Recovery....85
5.1.6.1 Overall Protection of Human Health and the Environment.... 85
5.1.6.2 Compliance with ARARs.... 86
5.1.6.3 Long-Term Effectiveness.... 86
5.1.6.4 Reduction of Toxicity, Mobility or Volume.... 87
5.1.6.5 Short-Term Effectiveness.... 88
5.1.6.6 Implementability.... 89
5.1.6.7 Cost.... 90
5.1.7 Alternative 6N – Full Removal of Materials Exceeding the PRG, Institutional Controls and Monitored Natural Recovery....90
5.1.7.1 Overall Protection of Human Health and the Environment.... 90
5.1.7.2 Compliance with ARARs.... 90
5.1.7.3 Long-Term Effectiveness.... 91
5.1.7.4 Reduction of Toxicity, Mobility or Volume.... 92

5.1.7.5 Short-Term Effectiveness ... 92
5.1.7.6 Implementability ... 93
5.1.7.7 Cost ... 94
5.2 Area South of I-10 ... 94
5.2.1 Alternative 1S – No Further Action ... 94
5.2.1.1 Overall Protection of Human Health and the Environment ... 94
5.2.1.2 Compliance with ARARs ... 95
5.2.1.3 Long-Term Effectiveness ... 95
5.2.1.4 Reduction of Toxicity, Mobility or Volume ... 95
5.2.1.5 Short-Term Effectiveness ... 95
5.2.1.6 Implementability ... 95
5.2.1.7 Cost ... 95
5.2.2 Alternative 2S – Institutional Controls ... 96
5.2.2.1 Overall Protection of Human Health and the Environment ... 96
5.2.2.2 Compliance with ARARs ... 96
5.2.2.3 Long-Term Effectiveness ... 96
5.2.2.4 Reduction of Toxicity, Mobility or Volume ... 96
5.2.2.5 Short-Term Effectiveness ... 97
5.2.2.6 Implementability ... 97
5.2.2.7 Cost ... 97
5.2.3 Alternative 3S – Enhanced Institutional Controls ... 97
5.2.3.1 Overall Protection of Human Health and the Environment ... 97
5.2.3.2 Compliance with ARARs ... 97
5.2.3.3 Long-Term Effectiveness ... 97
5.2.3.4 Reduction of Toxicity, Mobility or Volume ... 98
5.2.3.5 Short-Term Effectiveness ... 98
5.2.3.6 Implementability ... 98
5.2.3.7 Cost ... 98
5.2.4 Alternative 4S – Removal and Off-site Disposal ... 99
5.2.4.1 Overall Protection of Human Health and the Environment ... 99
5.2.4.2 Compliance with ARARs ... 99
5.2.4.3 Long-Term Effectiveness ... 99
5.2.4.4 Reduction of Toxicity, Mobility or Volume ... 99

5.2.4.5 Short-Term Effectiveness ... 99
5.2.4.6 Implementability ... 100
5.2.4.7 Cost ... 100

6 COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES ... 101
6.1 Area North of I-10 ... 101
6.1.1 Threshold Criteria ... 101
6.1.2 Long-Term Effectiveness ... 101
6.1.3 Reduction of Toxicity, Mobility or Volume ... 104
6.1.4 Short-Term Effectiveness ... 105
6.1.5 Implementability ... 106
6.1.6 Cost ... 107
6.1.7 Summary of Comparative Benefits and Risks ... 107
6.2 Area South of I-10 ... 108
6.2.1 Long-Term Effectiveness ... 109
6.2.2 Reduction of Toxicity, Mobility and Volume ... 109
6.2.3 Short-Term Effectiveness ... 109
6.2.4 Implementability ... 110
6.2.5 Cost ... 110
6.2.6 Summary of Comparative Benefits and Risks ... 110

7 REFERENCES ... 112

List of Tables

Table 3-1 Applicable or Relevant and Appropriate Requirements Summary
Table 4-1a Selected Sediment Capping Projects
Table 4-1b Selected Sediment Dredging Projects
Table 4-2 Release Case Studies
Table 4-3 Summary of Quantities and Durations – Area North of I-10
Table 4-4 Summary of Construction Emissions Factors – Area North of I-10
Table 4-5 Summary of Worker Risk Factors – Area North of I-10
Table 4-6 Summary of Quantities and Durations – Area South of I-10
Table 4-7 Summary of Construction Emissions Factors – Area South of I-10

Table 4-8 Summary of Worker Risk Factors – Area South of I-10
Table 5-1 Detailed Evaluation of Remedial Alternatives – Area North of I-10
Table 5-2 Detailed Evaluation of Remedial Alternatives – Area South of I-10
Table 6-1 Summary of Detailed Evaluation

List of Figures

Figure ES-1 Overall Project Cost and Effectiveness
Figure 1-1 Vicinity Map
Figure 1-2 USEPA's Preliminary Site Perimeter and Surrounding Area
Figure 2-1 Land Use in the Vicinity of USEPA's Preliminary Site Perimeter
Figure 2-2 Habitats in the Vicinity of USEPA's Preliminary Site Perimeter
Figure 2-3 $TEQ_{DF,M}$ Concentrations in Surface Sediment
Figure 2-4 $TEQ_{DF,M}$ Concentrations in Sediment Cores
Figure 2-5 $TEQ_{DF,M}$ Concentrations in Soil South of I-10
Figure 2-6 Armored Cap As-Built Drawing
Figure 3-1 $TEQ_{DF,M}$ Concentrations in Surface Sediment Outside Armored Cap Compared to Hypothetical Recreational Visitor PRG
Figure 3-2 $TEQ_{DF,M}$ Concentrations in Sediment Cores Outside Armored Cap Compared to Hypothetical Recreational Visitor PRG
Figure 3-3 $TEQ_{DF,M}$ Concentrations in Surface/Soil Sediment Inside Armored Cap and South of Area of Investigation South of I-10 Compared to Hypothetical Future Outdoor Commercial Worker PRG
Figure 3-4 $TEQ_{DF,M}$ Concentrations in Soil/Sediment Cores Inside Armored Cap South of I-10 Compared to Hypothetical Future Outdoor Commercial Worker PRG
Figure 3-5 $TEQ_{DF,M}$ Concentrations in Soil in the Area of Investigation Compared to Hypothetical Future Construction Worker PRG
Figure 4-1 Plan View – Alternative 3N, Permanent Cap
Figure 4-2 Cross Section A-A' - Alternative 3N
Figure 4-3 Plan View – Alternative 4N
Figure 4-4 Cross Sections A-A' and B-B' – Alternative 4N
Figure 4-5 Plan View – Alternative 5N
Figure 4-6 Cross Sections – A-A' and B-B' - Alternative 5N
Figure 4-7 Plan View – Alternative 5aN

Figure 4-8	Cross Sections – A-A' through D-D' - Alternative 5aN
Figure 4-9	Plan View – Alternative 6N
Figure 4-10	Cross Sections A-A', B-B', C-C', and D-D' – Alternative 6N
Figure 4-11	Preliminary Remedial Action Areas South of I-10
Figure 6-1a	Comparison of Model-Predicted Surface Sediment (top 6 inches) TCDD Concentrations in Year 21, Averaged over USEPA's Preliminary Site Perimeter and TCRA Site Footprint
Figure 6-1b	Comparison of Model-Predicted Surface Sediment (top 6 inches) TCDD Concentrations in Year 21, Averaged by River Mile
Figure 6-2	Comparison of Model-Predicted Annual Average Water Column TCDD Concentrations (Year 21) over USEPA's Preliminary Site Perimeter and TCRA Site Footprint
Figure 6-3	Comparison of Model-Predicted Annual Average Water Column TCDD Concentrations (Year 1) over USEPA's Preliminary Site Perimeter and TCRA Site Footprint

List of Appendices

Appendix A	Chemical Fate and Transport Modeling
Appendix B	Hydrodynamic Cap Modeling
Appendix C	Remedial Alternatives Cost Development

LIST OF ACRONYMS AND ABBREVIATIONS

1V:3H	1 vertical to 3 horizontal
2H:1V	2 horizontal to 1 vertical
3H:1V	3 horizontal to 1 vertical
5H:1V	5 horizontal to 1 vertical
AOC	Administrative Settlement Agreement and Order on Consent for Removal Action: CERCLA Docket No. 06-12-10
ARAR	Applicable or Relevant and Appropriate Requirements
BAT	Best Available Technology Economically Achievable
BCT	Best Conventional Pollution Control Technology
BERA	Baseline Ecological Risk Assessment
BHHRA	Baseline Human Health Risk Assessment
BMP	Best Management Practice
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
Cfs	cubic feet per second
CMP	Coastal Management Plan
cm/year	centimeters per year
CNRA	Coastal Natural Resource Area
COC	chemical of concern
COPC	chemical of potential concern
CSM	Conceptual Site Model
CWA	Clean Water Act
Cy	cubic yard
EAM	Exposure Assessment Memorandum
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
FS	Feasibility Study
FS Report	Feasibility Study for the San Jacinto River Waste Pits Superfund Site
GLO	Texas General Land Office
GRA	General Response Action

HSC	Houston Ship Channel
I-10	Interstate Highway 10
ICs	Institutional Controls
IP	International Paper Company
MCL	Maximum Contaminant Level
MIMC	McGinnes Industrial Maintenance Corporation
mm/year	millimeters per year
MNR	Monitored Natural Recovery
MOU	Memorandum of Understanding
MSL	mean sea level
NAVD88	North American Vertical Datum of 1988
NCP	National Contingency Plan
ng/kg	nanograms per kilogram
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOx	nitrogen oxides
NFIP	National Flood Insurance Program
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRHP	National Register of Historic Places
NRRB	National Remedy Review Board
NSR	net sedimentation rate
OMM	Operations, Monitoring, and Maintenance
OSHA	Occupational Safety and Health Administration
PCB	polychlorinated biphenyl
PRG	protective concentration level
PM	particulate matter
$PM_{2.5}$	fine particle particulate matter
POTW	publically owned treatment works
PPE	personal protective equipment
PRG	preliminary remedial goals
Proposed Plan	proposed remedial action plan for the SJRWP Site
PSCR	Preliminary Site Characterization Report

RACR	Removal Action Completion Report
RAL	remedial action level
RAM	Remedial Alternatives Memorandum
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RME	Reasonable Maximum Exposure
ROD	Record of Decision
ROW	right-of-way
S/S	solidification and stabilization
Site	San Jacinto River Waste Pits Superfund Site
SJRF	San Jacinto River Fleet
SJRWP	San Jacinto River Waste Pits
SMA	sediment management area
SPME	solid phase micro extraction
SWAC	surface-weighted average concentration
SWPPP	Storm Water Pollution Prevention Plan
TBC	to-be-considered
TCCC	Texas Coastal Coordination Council
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TCDF	2,3,7,8-tetrachlorodibenzofuran
TCEQ	Texas Commission on Environmental Quality
TCMP	Texas Coastal Management Plan
TCRA	time critical removal action
TEQ	toxic equivalents
$TEQ_{DF,M}$	TEQ concentration calculated for dioxin and furan congeners using toxicity equivalency factors for mammals
TES	threatened and endangered species
TMDL	total maximum daily load
TMV	toxicity, mobility or volume
TPDES	Texas Pollutant Discharge Elimination System
TSHA	Texas State Historical Association
TxDOT	Texas Department of Transportation

T&E	threatened and endangered
UAO	Unilateral Administrative Order for Remedial Investigation/Feasibility Study: CERCLA Docket No. 06-03-10
UECA	Uniform Environmental Covenants Act
USACE	U.S. Army Corps of Engineers
U.S.C.	U.S. Code
USDL	U.S. Department of Labor
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Services

EXECUTIVE SUMMARY

This report presents the Feasibility Study (FS) for the San Jacinto River Waste Pits (SJRWP) Superfund Site (Site) in Harris County Texas, and was prepared as a companion to the related Remedial Investigation (RI) Report (Integral and Anchor QEA 2013). The RI Report was prepared on behalf of McGinnes Industrial Maintenance Corporation (MIMC) and International Paper Company (IP) and in response to a Unilateral Administrative Order (UAO) issued by the U.S. Environmental Protection Agency (USEPA), Docket No. 06-03-10.

This FS Report presents remedial alternatives for two areas within the study area perimeter designated by USEPA for purposes of the RI/FS investigation (USEPA's Preliminary Site Perimeter).

One area is located north of Interstate Highway (I-10) where impoundments used for the disposal of paper mill waste (Northern Impoundments) are located. A time critical removal action (TCRA) has been implemented to construct an armored cap to isolate and contain waste in those impoundments (Armored Cap). The FS Report presents seven remedial alternatives for the Northern Impoundments (Alternatives 1N, 2N, 3N, 4N, 5N, 5aN, and 6N). The alternatives range from continued maintenance of the existing Armored Cap (Alternative 1N) to full removal of waste and impacted materials (Alternative 6N).

The second area is located on the peninsula south of I-10 to the west of Market Street, where various marine and shipping companies have operations; certain portions of the area of investigation south of I-10 may have been used for disposal of paper mill waste (as well as other wastes) in the 1960s. The remedial alternatives for this area (Alternatives 1S to 4S) address three distinct locations in which subsurface soils contain dioxins at levels above the preliminary remediation goal (PRG) for a hypothetical future construction worker. There are no risks to ecological receptors from dioxins.

The Site and Site History

The SJRWP Site was added to the National Priorities List (NPL) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in 2008. USEPA's Preliminary Site Perimeter encompasses several impoundments and surrounding in-water and upland areas. The impoundments are located on the western side of the San Jacinto River, in Harris County, Texas, north and south of I-10 where I-10 crosses the San Jacinto River. The impoundments were built in the mid-1960s for disposal of paper mill wastes that were barged from the Champion Paper Inc. paper mill in Pasadena, Texas.

Large scale groundwater extraction by others resulting in regional subsidence of land in the vicinity of the SJRWP Site resulted in exposure of the contents of the Northern Impoundments to surface waters. The Northern Impoundments were the subject of a TCRA, discussed below, that since its completion in 2011 has capped and isolated waste material and impacted sediments.

The area of investigation south of I-10 is an upland area, and the site of a former impoundment. The impoundment south of I-10 is not currently and has not been in contact with surface water. Since the 1960s, a variety of industrial and other activities have taken place on the upland area south of I-10. Most of the peninsula is currently in industrial or commercial use by marine services companies, with some parcels currently unused.

Stabilization and Isolation of the Northern Impoundments

MIMC and IP implemented a TCRA to stabilize and isolate materials within the Northern Impoundments. The TCRA was completed in 2011 pursuant to the terms of an Administrative Settlement Agreement and Order on Consent for Removal Action: CERCLA Docket No. 06-12-10 (AOC; USEPA 2010a). It included construction of an armored cap that was designed in accordance with U.S. Army Corps of Engineers (USACE) and USEPA guidelines and capping guidance (USACE 1998; USEPA 2005) (Armored Cap). The TCRA also included installation of fencing around the TCRA Site, establishment of access controls, and the posting of warning signs.

The Armored Cap includes layers of armor stone, geotextile and geomembrane and is constructed over an area of approximately 15.7 acres. It was designed and constructed at a cost of more than $9 million. The Armored Cap was designed to withstand a 100-year storm event with an additional factor of safety to ensure its long-term protectiveness. The storm event defines the depth of water and the currents that the cap armor layer must resist. Although a 100-year event was specified for the TCRA design, events up to the 500-year storm were evaluated for the FS in order to assess the potential risk of an even larger storm, and the Armored Cap was determined to withstand this larger-magnitude storm (Appendix B).

Since being completed in July 2011, the Armored Cap has generally isolated and contained impacted material. However, in December 2015 a small area (approximately 22 feet by 25 feet) on the northwest part of the cap was found to be deficient in armor rock material. This deficiency resulted in exposing the underlying paper mill waste material to the San Jacinto River. Sampling of the exposed waste material found that it contained dioxin over 43,000 ng/kg TEQ dioxin, while sampling from the nearby undisturbed areas of the cap did not show elevated levels of waste materials containing dioxins. Repairs of this rock deficient area were completed in January 2016 by installing a geotextile fabric over the area and covering it with armor stone.

The Armored Cap, and associated fencing, access controls and signs have been routinely inspected and maintained pursuant to a USEPA-approved Operations, Monitoring, and Maintenance (OMM) Plan. The OMM Plan was developed to address conditions that USACE and USEPA cap design guidance expressly presumes could occur post-construction (such as movement of rock cover in localized areas of the cap). The OMM Plan requires periodic monitoring, as well as monitoring following key storm events, to identify the need for possible cap maintenance and procedures to implement appropriate repair activities (USEPA 2005; USACE 1998).

In July 2012, early in the post-construction period, disruption of a localized area of the armor layer (the rock above the geotextile layer) of the Armored Cap occurred and was promptly addressed in accordance with the approved OMM Plan and USACE and USEPA guidance. The affected areas totaled about 200 square feet, or 0.03 percent of the overall area of the Armored Cap.

Maintenance events during the first few years after sediment cap construction are not unusual. At least two other sediment caps with demonstrated performance over the last 20+ years have followed this progression. The St. Paul Waterway cap (USEPA 2004b) and the Eagle Harbor cap (USEPA 2012d), constructed in the late 1980s and early 1990s respectively, required some early maintenance in their first few years. Subsequent monitoring has demonstrated the continued protectiveness of these sediment caps.

The Armored Cap's design and construction were the subject of a post-construction evaluation by MIMC and IP and a separate assessment by USEPA and USACE (USACE 2013). Based on this review, the USACE recommending enhancements (e.g., placing additional armor rock and constructing flatter slopes) to further ensure the long-term protectiveness of the Armored Cap. In January 2014, the Respondents implemented all of the USACE recommendations (Anchor QEA 2014).

Remedial Action Objectives and Protective Concentration Levels

Remedial Action Objectives (RAOs) for the Site were developed by the Respondents in collaboration with USEPA. Additionally, PRGs for soil and sediment were developed as part of the RI/FS process. The PRGs are consistent with reasonably anticipated future uses and applicable to the areas north and south of I-10 for which remedial alternatives were developed. The PRG for dioxin/furan in sediment is 200 ng/kg TEQ (hypothetical recreational visitor, non-cancer HQ = 1) and for dioxin/furan in soil is 240 ng/kg TEQ (hypothetical construction worker, non-cancer hazard HQ = 1).

Principal Threat Waste

The NCP establishes an expectation that EPA will use treatment to address the principal threats posed by a site wherever practicable (NCP § 300.430(a)(1)(iii)(A)). In general, principal threat wastes are those source materials considered to be highly toxic or highly mobile which generally cannot be contained in a reliable manner or would present a significant risk to human health or the environment should exposure occur. The "principal threat" concept is applied to the characterization of "source materials" at a Superfund site. At the Site, the northern waste pits sediment contain dioxin/furan over 43,000 ng/kg TEQ, and the Southern Impoundment soils contains dioxin/furan over 50,000 ng/kg TEQ. The northern waste pits maximum dioxin/furan concentration is 215 times higher than the non-cancer hazard based PRG, and the Southern Impoundment maximum dioxin/furan concentration is 208 times higher than its non-cancer hazard based PRG. The non-cancer hazard index for exposure to sediments (recreational visitor scenario) at the Site 60, which is more than an order of magnitude greater that the acceptable hazard index of 1. Dioxin/furans are highly persistence chemicals and will not breakdown for hundreds of years. While there is considerable uncertainty regarding biodegradation of dioxins/furans, however, by one estimate the dioxin/furans will remain at the Site above the PRGs for approximately 750 years (Khoury, 2016).

The Site is located in the San Jacinto River, which has experienced a number of severe storms and floods in the past. For example, the 1994 flood exceeded the 100-year return period storm, resulted in severe riverbed scour while cutting of new channels outside of the river bed, destroyed or damaged thousands of homes, and undermining and rupturing pipelines both inside and outside of the river channel. The 1994 storm crested at 27.09 feet at the Sheldon, Texas gauge located about five miles upstream of the Site. Previous storm resulted in even higher crests of 31.5 feet 1940 and 32.90 feet in 1929.

Because of the high levels of dioxin/furan, which are over two orders of magnitude higher than the acceptable concentration, and its' highly toxic and persistence nature, there is a significant risk to human health or the environment should exposure occur. With the regular occurrence of severe storms and flooding in the area, there is uncertainty that the waste material can be reliably contained over the long term. Therefore, the dioxin/furan waste at the San Jacinto River Waste Pits Superfund Site is considered a principle threat waste.

Remedial Alternatives for Area North of I-10

Remedial technologies presented in this FS Report were subjected to an initial screening process before being developed and included in the final set of remedial alternatives that are discussed in this FS Report, or were included at USEPA's direction. For the area north of I-10, the remedial alternatives focus on containment, treatment, removal, and/or a combination of containment, treatment and removal, together with Institutional Controls (ICs) to achieve a range of post-remedy surface-weighted average concentrations (SWACs). All alternatives recognize the existence of the Armored Cap.

The alternatives developed and presented in this FS Report for the area north of I-10 include:

- **Alternative 1N – Armored Cap and Ongoing OMM (No Further Action),** which assumes the Armored Cap would remain in place, together with fencing, warning signs and access restrictions established as part of the TCRA, and would be subject to ongoing OMM. The estimated cost of this alternative is $9.5 million. This estimate includes the cost of Armored Cap design and construction and USEPA 5-year reviews; these same costs are included in the estimate for each of the other alternatives for the area north of I-10.

- **Alternative 2N – Armored Cap, ICs and Monitored Natural Recovery (MNR),** which includes the actions described under Alternative 1N, ICs in the form of deed restrictions and notices, and periodic monitoring to assess the effectiveness of sediment natural recovery processes. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. This alternative is estimated to cost $10.3 million.

- **Alternative 3N – Permanent Cap, ICs and MNR,** which includes the actions described under Alternative 2N plus additional enhancements to the Armored Cap, many of which have already been implemented during the January 2014 efforts, consistent with the USACE recommendations. This alternative will increase the long-term stability of the Armored Cap consistent with permanent isolation of impacted materials (Permanent Cap) and meet or exceed USACE design standards. The Permanent Cap will use rock sized for the "No Displacement" design scenario, which is more conservative than the "Minor Displacement" scenario used in the Armored Cap's design. This remedial alternative also includes additional measures to protect the Permanent Cap from potential vessel traffic (e.g., rock berm). This alternative would require an estimated 2 months of construction at an estimated cost of $12.5 million. An off-site staging area may be required for management of rock armor materials, similar to that which was utilized during the TCRA construction.

However, the exact location and configuration of the staging area are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 4N – Partial Solidification/Stabilization, Permanent Cap, ICs and MNR,** provides for solidification and stabilization (S/S) of the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. This alternative also includes the actions described under Alternative 3N; however, about 23 percent of the Armored Cap (2.6 acres above the water surface and 1.0 acre in submerged areas) would be removed to provide for S/S of the most highly contaminated material. About 52,000 cubic yards (cy) of materials with $TEQ_{DF,M}$ that exceeds a concentration 13,000 nanograms per kilogram (ng/kg), would undergo S/S. After the S/S is completed, the Permanent Cap would be re-constructed and the same ICs and MNR as in Alternatives 2N and 3N would be implemented. This alternative would require an estimated 17 months of construction to complete and is estimated to cost $23.2 million. An off-site staging area may be required for management of rock armor materials, stabilization reagents and associated treatment equipment. However, the exact location and configuration of the staging area are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 5N – Partial Removal, Permanent Cap, ICs and MNR,** provides for removal of the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. The Armored Cap would be partially removed and the same 52,000 cy of material that would undergo S/S under Alternative 4N would instead be excavated for off-site disposal. After the removal was completed, the Permanent Cap would be re-constructed and the same ICs and MNR that are part of Alternatives 2N to 4N would be implemented. This alternative would require an estimated 13 months of construction at an estimated cost of $38.1 million. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. The exact location, configuration, siting and operational impacts, as well as potential delivery restrictions by the receiving facility (e.g., tons per day) are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 5aN - Partial Removal of Materials Exceeding the PRG, Permanent Cap, ICs and MNR,** in which all material beneath the Armored Cap in any location where the water depth is 10-feet or less and which has a $TEQ_{DF,M}$ at or above the PRG for a hypothetical recreational visitor of 220 ng/kg[1] – about 137,600 cy – would be excavated for off-site disposal. To implement this alternative, about 11.3 acres (72 percent) of the Armored Cap would be removed to allow for this material to be dredged. After excavation of the material, the remaining areas of the Armored Cap would be enhanced to create a Permanent Cap, and the same ICs and MNR that are part of the preceding four alternatives would be implemented. This alternative would require an estimated 19 months for construction and has an estimated cost of $77.9 million. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. The exact location, configuration, siting and operational impacts, as well as potential delivery restrictions by the receiving facility (e.g., tons per day) are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 6N – Full Removal of Materials Exceeding the PRG, ICs and MNR,** all material above the PRG of 200 ng/kg located beneath the Armored Cap or at depth in an area to the west would be removed. This would involve removal of the existing Armored Cap in its entirety and the removal of approximately 200,100 cy of material. The removal could be completed in stages or sections to limit the exposure of the uncovered sections of the waste pits to potential storms. The design approach for removal in stages will be determined in the Remedial Design. Raised berms, sheet piles, and silt curtains in addition to removal in the dry to the extent practicable will be used to reduce the re-suspension and spreading to the removed material. The berms would be armored on the external site with armor material removed from the areas that have geotextile present. Residual concentrations of contaminants following excavation and dredging will be covered by at least two layers of clean fill to limit intermixing of residual material with the clean fill This alternative would require an estimated 16 months of construction at an estimated cost of $99.2 million. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. The exact location, configuration, siting and operational impacts, including severe weather, as well as potential delivery restrictions by the receiving facility (e.g., tons per day) are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

[1] In defining this alternative, USEPA included an additional requirement that all material exceeding 13,000 ng/kg $TEQ_{DF,M}$, regardless of water depth, would be removed. All locations that exceed 13,000 ng/kg $TEQ_{DF,M}$ are in areas with 10-feet of water or less. Thus, the horizontal boundary defining this alternative (the 10-foot water depth) includes all locations exceeding 13,000 ng/kg $TEQ_{DF,M}$.

Each of these alternatives meets the CERCLA threshold criteria that a remedy: 1) provides for overall protection of human health and the environment; and 2) complies with the Applicable or Relevant and Appropriate Requirements (ARARs) identified for the Site.

Comparative Evaluation of Alternatives for Area North of I-10

Alternatives 1N and 2N rely on continued containment of materials exceeding the PRGs within the existing Armored Cap, as enhanced in 2014 to address the USACE's recommendations. These two alternatives each include a requirement, based on the approved OMM Plan, to monitor and maintain the Armored Cap in accordance with USACE and USEPA guidance to ensure the long-term effectiveness of the cap system.

Alternative 3N includes the features of Alternatives 1N and 2N, together with construction of a Permanent Cap that exceeds USACE and USEPA design guidance by placing additional armor rock and constructing flatter slopes. In addition, the Permanent Cap uses larger rock sized for the "No Displacement" design scenario, which more conservative than the "Minor Displacement" scenario used in the Armored Cap's design, and other CERCLA caps, such as Onondaga Lake and Fox River (Appendix B). In addition, Alternative 3N includes the construction of a protective perimeter barrier or other measures around the perimeter of the Permanent Cap to address concerns regarding potential damage from vessel traffic.

Alternatives 1N, 2N, and 3N are containment alternatives that provide substantial long-term protectiveness while avoiding environmental impacts applicable to Alternatives 4N, 5N, 5aN and 6N, all of which require disruption of the existing Armored Cap to conduct stabilization or removal/disposal of impacted materials. However, Alternatives 1N, 2N, and 3N do not provide any treatment or removal of the dioxin/furan principle threat waste. Alternative 3N provides additional long-term protectiveness compared to Alternatives 1N and 2N due to the additional cap enhancements that meet or exceed USACE design standards and measures to minimize potential damage to the Permanent Cap from vessel traffic. Alternative 6N provides the greatest long-term protectiveness and effectiveness because the waste material, except for the dredge residuals, would be permanently removed from the San Jacinto River and there would be no potential for a future release from the Site, and neither would there be any concerns regarding the long term viability and effectiveness of a maintenance program that would have to endure for an extremely long time, or 750 years by one estimate. Alternative 6N also provides for removal of the dioxin/furan principle threat waste.

Engineering analysis of the stability of a Permanent Cap (Alternative 3N) has determined that the cap may remain protective when subjected to the erosive forces under any of the flow scenarios (including a 500-year flood event) evaluated in the hydrodynamic modeling

(Appendix B). In situ capping, as discussed in USEPA and USACE guidance (USEPA 2005; USACE 1998) and in Table 4-1a, is a demonstrated technology that has been selected by USEPA for sediment remediation sites across the United States. However, the Site's location within the San Jacinto River creates an uncertainty regarding the ability of an engineered cap to reliably contain the dioxin waste over the very long time that the dioxin will remain hazardous. By one estimate the dioxin will remain hazardous for approximately 750 years. The uncertainty comes from the severe storms and floods that have occurred in the area, and the potential for barge strikes to compromise the cap. The potential for barge strikes is heighted because of the increased barge traffic after the completion of the temporary armored cap.

Alternatives 4N, 5N, 5aN, and 6N include disruption of the existing Armored Cap in order to conduct treatment or removal of materials beneath the cap. These alternatives employ design, engineering and operational controls to mitigate the resuspension of impacted sediments that occurs when using these remedial technologies. Removal technologies have been used at sediment sites listed on Table 4-1b. Alternatives 4N and 5N would stabilize (4N) or remove (5N) materials with $TEQ_{DF,M}$ greater than the level set by USEPA of 13,000 ng/kg. Alternatives 5aN and 6N would remove some (5aN) or all (6N) materials that exceed the PRG of 220 ng/kg for a hypothetical recreational visitor. Alternative 4N would stabilize 52,000 cy of the waste material from beneath the Armored Cap, while Alternative 5N, 5aN, and 6N would remove and dispose of off-site volumes of material ranging from 52,000 cy (Alternative 5N), to 137,600 cy (Alternative 5aN) to 200,100 cy (Alternative 6N). Alternatives 5N and 5aN may reduce the amount of long-term OMM associated with the capping and treatment-based alternatives (1N thorough 4N), while 6N would eliminate OMM completely.

Alternative 3N has an estimated construction duration of 2 months and would likely require an off-site staging area for armored rock. Alternatives 4N, 5N, 5aN, and 6N have estimated construction durations ranging from 13 to 19 months. Each of these alternatives would require the establishment, and potential permitting of an off-site facility for sediment and material handling. For Alternatives 5N, 5aN, and 6N, this facility would be utilized for processing and managing dredged sediments. The availability and location of an off-site facility could impact the implementability, duration, and costs of these alternatives and are beyond the scope of the FS.

Implementation of Alternatives 4N, 5N, 5aN, or 6N would require removing all or part of the Armored Cap and either excavation, dredging, or stabilizing the underlying waste deposits. Stabilization under Alternative 4A is consistent with USEPA's preference for treatment. However, despite the use of robust engineering and operational controls in conjunction with these alternatives, experience at other sediment sites indicates that resuspension of impacted sediments and release of waste material and dioxins/furans into the water column will likely occur, although to a reduced extent. These issues have been documented at other sediment remediation projects (Table 5-2) in spite of efforts made to prevent or control such releases (USACE 2008a; Bridges et al. 2010; Anchor Environmental 2005; Anchor QEA and Arcadis 2010). Such releases may result in increased fish tissue concentrations of contaminants for several years following completion of dredging (Patmont et al. 2013). Moreover, the conservative design necessary to overcome the higher level of uncertainty associated with the implementation of these removal/disposal alternatives can result in cost increases.

Best Management Practices (BMPs) may be successful in mitigating potential resuspension and release under normal flow conditions. During construction, however, BMPs could be overwhelmed during significant storm and flood events. For alternatives 4N, 5N, 5aN, and 6N, which require removal of the Armored Cap during construction, the consequences of flooding could be significant as the exposed and disturbed materials would be at risk of spreading beyond the remedial area. For the estimated construction durations of these alternatives, there is a 30 to 40 percent likelihood[1] that such a flood could occur during construction. The potential for release during implementation is a factor that USEPA guidance requires be considered during the comparative net risk analysis of remedial alternatives. See USEPA 2005, Section 6.5.5 and Section 7.4 for reference. Therefore, these alternatives will include design and construction methodologies to mitigate and reduce the impact of storms during construction. These methodologies may include armor cap removal in sections, operational controls, etc.

For short-term effectiveness, Alternatives 1N and 2N are most favorable, followed by Alternative 3N. Short-term effectiveness ranks high for Alternatives 1N and 2N because these alternatives do not entail active construction. Alternative 3N ranks lower than Alternatives 1N and 2N for short-term effectiveness because it includes active construction considerations such as truck traffic, worker safety, water quality, and construction equipment emissions of particulate matter (PM), greenhouse gases, and ozone. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10.

[1] Likelihood of flooding assessed by evaluating the duration of construction as compared to flood frequency, assuming a water surface elevation that could overtop perimeter controls such as berms and sheetpiles. See Appendix B and FS Report Section 5 for additional details and discussion.

Alternatives 4N, 5N, 5aN, and 6N also involve potential water quality impacts, worker safety risks, and air emission impacts that are estimated to be more than 8 to 20 times greater[2] than for Alternative 3N. Traffic and community impacts for Alternatives 4N, 5N, 5aN, and 6N (measured as truck trips) are estimated to range from 6 to nearly 70 times greater than for Alternative 3N and may not fully account for truck trips associated with operation of an offsite materials management facility. Alternatives 4N, 5N, 5aN, and 6N all provide either treatment or removal of principle threat waste, at least for a portion of the waste material. Alternative 4N includes treatment (solidification/ stabilization) for about 25% of the volume of the most highly contaminated portion of the waste. Alternative 5N and 5aN both include partial removal of the most highly contaminated waste, with Alternative 5N accounting for 25% of the volume, and Alternative 5aN accounting for about 2/3 of the waste volume. Alternative 6N includes full removal of the principle threat waste.

Comparative Cost Effectiveness of the Alternatives for the Area North of I-10

Pursuant to the USEPA's 1999 guidance, A Guide to Preparing Proposed Plans, Records of Decision, and Other Remedy Selection Documents, "cost-effectiveness is concerned with the reasonableness of the relationship between the effectiveness afforded by each alternative and its costs compared to other available options." In addition, "if the difference in effectiveness is small but the difference in cost is very large, a proportional relationship between the alternatives does not exist" as discussed in the preamble to National Contingency Plan (NCP) (Federal Register 1990).

Costs for the remedial action alternatives range from $9.5 to over $99 million.

Alternatives 1N and 2N have similar costs, primarily related to long-term OMM of the Armored Cap. Alternative 3N has a higher cost than Alternatives 1N and 2N as it also includes construction of the Permanent Cap and a protective barrier to ensure the long-term integrity of the Permanent Cap.

Costs for Alternatives 4N, 5N, 5aN, and 6N are higher than for Alternatives 1N, 2N, and 3N. This reflects the challenges of establishing and operating an off-site staging and processing area, removal of the Armored Cap, in situ treatment or excavation and associated engineering controls, the quantity of materials being addressed, the duration of work, and the high cost of transportation and disposal of impacted sediments.

[2] Safety risks assessed based on estimated durations and labor needs for each alternative, using U.S. Department of Labor safety statistics. Air emissions assessed based on hours of equipment usage estimated for each alternative. See FS Report Section 4 for additional details.

Alternatives 1N, 2N, and 3N provide an equal reduction in the dioxins and furans in sediments in the river within USEPA's Preliminary Site Perimeter. For Alternatives 4N, 5N, 5aN, and 6N, the SWAC for dioxins and furans in sediments in the river are predicted to increase the short-term from sediment re-suspension construction-related impacts (e.g., cap removal, disturbance of material below waterline, etc.). Alternatives 5N and 5aN would remove some while 6N would remove all impacted materials with higher dioxin/furan concentrations, but possible impacts from re-suspension during construction could potentially reduce the short-term protectiveness of the remedy. These alternatives are also incrementally and substantially more expensive because of their complexity and duration. Even if it were to be assumed that no re-suspension, other impacts, or residuals would occur during implementation of Alternative 4N, 5N, 5aN, or 6N (which experience with other environmental dredging projects demonstrates will not likely be the case), no incremental protectiveness in the SWAC would likely occur as a result of the implementation of any of these alternatives.

Remedial Alternatives for Area South of I-10

The area south of I-10 is part of a peninsula on which industrial activity has occurred since at least the early 1960s. In contrast with the area to the north of I-10, the peninsula south of I-10 contains active operations of several shipping and marine industrial services businesses, with the area serving as a transport hub and as a location for barge or ship maintenance, cleaning and painting. Changes in the distribution of materials, locations of soil disturbance and staining, development of buildings or other structures, and evolution of roads and tracks throughout the southern peninsula area, indicate that the peninsula south of I-10 has been a busy industrial community in the decades after any disposal of paper mill wastes in the mid-1960s took place.

Three dioxin and furan source types have been identified in soils of the area of investigation south of I-10, only one of which has a fingerprint that is similar to the paper mill wastes contained in the North Impoundments. Another source is from general urban background, such as fuel combustion and other common municipal activities, or specific local sources. A third source type has a fingerprint that is distinct from the other two sources, and affects only soils in the area of investigation on the peninsula south of I-10. The nature and origin of this dioxin and furan source are unknown.

There are no risks to ecological receptors from dioxins and furans in the area of investigation south of I-10. The only risks associated with the disposal of dioxins and furans associated with paper mill wastes in the area of investigation south of I-10 was for a hypothetical future construction worker who might, in three discrete locations, come into contact with the dioxins and furans within the upper 10 feet of soil. The PRG for $TEQ_{DF,M}$ protective of a hypothetical future construction worker for $TEQ_{DF,M}$ was calculated to be 450 ng/kg, and is applicable to the average concentration in a soil column of 10 feet.

Remedial alternatives were developed for the three locations in the area south of I-10 where the average $TEQ_{DF,M}$ concentration in the upper 10-feet of soil below grade exceeds the PRG for the hypothetical future construction worker. $TEQ_{DF,M}$ concentrations in the upper 10-feet of soil exceed the PRG at four locations, with the highest $TEQ_{DF,M}$ concentrations occurring at 5-feet below the ground surface or deeper (Figure 3-5). Remedial alternatives developed for the area south of I-10 include:

- Alternative 1S – No Further Action
- Alternative 2S – ICs
- Alternative 3S – Enhanced ICs
- Alternative 4S – Removal and Off-site Disposal

The costs for these alternatives are $140,000 (Alternative 1S – No Further Action), $270,000 (Alternative 2S – ICs), $660,000 (Alternative 3S – Enhanced ICs) and $9.9 million (Alternative 4S – Removal and Off-site Disposal).

Other than Alternative 1S, the remedial alternatives for the area south of I-10 meet both of the CERCLA threshold criteria as established in the NCP: protectiveness and compliance with ARARs. The potentially affected receptor (hypothetical future construction worker) would be protected from exposure to soil with elevated $TEQ_{DF,M}$ concentrations by warnings and restrictions (Alternatives 2S and 3S) or removal of impacted soil (Alternative 4S).

Alternative 4S offers the benefit of permanent removal of impacted soil from the 0- to 10-foot interval, but the risk management achieved by ICs is nearly equivalent, particularly with the addition of the physical markers that are part of Alternative 3S. Alternatives 2S and 3S would not require exposing impacted soil or transporting material off-site and would be simpler to implement. Excavation of impacted soil (Alternative 4S) would introduce short-term risks of exposure on-site and potentially off-site in the event of a release in route to the disposal facility. The cost of Alternative 4S, $9.9 million, is 15 times the cost of Alternative 3S and more than 35 times the cost of Alternative 2S. Alternative 4S does not satisfy the NCP requirement that a remedy be cost-effective, because it does not provide additional protectiveness in comparison to the disproportionate incremental cost, at least in the short term. For the long term, Alternative 4S does provide additional protectiveness because there is no possibility that erosion would expose high level wastes in the future. Alternative 4S is the only alternative that provides for treatment or removal of the principle threat waste material.

In summary, Alternative 4S offers an increase in long-term effectiveness by removing the impacted soil; however, there is an increased short-term risk of exposure and potential traffic accidents. Alternatives 2S and 3S mitigate potential risks associated with exposure to soil in the area south of I-10 with reduced short-term exposure risks and at costs commensurate with the potential risk associated with the impacted soil at depth, although with a reduced long term protectiveness.

1 INTRODUCTION

This Feasibility Study (FS) Report was prepared for the San Jacinto River Waste Pits (SJRWP) Superfund Site (Site) (Figures 1-1 and 1-2). The location of U.S. Environmental Protection Agency's (USEPA's) Preliminary Site Perimeter is shown in Figure 1-2. This FS Report builds upon the final Remedial Alternatives Memorandum (RAM), which presented the screening of remedial technologies and the development of preliminary remedial alternatives. The Draft RAM was conditionally approved by USEPA on November 14, 2012 (USEPA 2012b) and the revised, final version was submitted to USEPA on December 3, 2012 (Anchor QEA 2012b). This FS Report develops and evaluates remedial alternatives for the SJRWP Site based on the Remedial Action Objectives (RAOs) provided in the RAM and Remedial Investigation (RI) Report (Integral and Anchor QEA 2013), and based on results of the Baseline Human Health Risk Assessment (BHHRA) (Integral 2013b) and Baseline Ecological Risk Assessment (BERA) (Integral 2013a). The BERA and BHHRA were conditionally approved by USEPA on February 26, 2013 and May 22, 2013, respectively. The Final BERA and BHHRA were submitted to USEPA on May 6, 2013 and May 22, 2013, respectively.

1.1 Purpose and Organization of the Report

The FS Report evaluates remedial alternatives for the Site, and is consistent with specific guidance (USEPA 1988) as required by the Unilateral Administrative Order (UAO; USEPA 2009a). The identification and screening of remedial technologies, which the guidance includes as an element of the FS Report (Table 6-5, USEPA 1988), is discussed in the RAM (Anchor QEA 2012b), as was required by the UAO.

The remainder of Section 1 provides a summary of the regulatory background with respect to the Site. Section 2 provides a summary of Site information as presented in previous documents prepared and submitted in support of the RI/FS process, including a summary of the Site setting and history, the nature and extent of contamination, chemical fate and transport, results of the BERA and BHHRA, and the Conceptual Site Models (CSMs) for the SJRWP Site. The other sections of the FS Report address the following:

- Section 3 identifies the preliminary remediation goals (PRGs) described in the RI Report and identified by USEPA and describes the basis for the remedial action
- Section 4 describes the development of each remedial alternative
- Section 5 provides a detailed and comparative analysis of each remedial alternative
- Section 6 provides the comparative analysis of the remedial alternatives
- Section 7 provides the references

1.2 Regulatory Background

On March 19, 2008, the USEPA listed the SJRWP Site on the National Priorities List (NPL) under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund, due to presence of metals and dioxins and furans (Texas Commission on Environmental Quality [TCEQ] and USEPA 2006, 2008) in soils and sediments at the SJRWP Site. On November 20, 2009, USEPA issued a UAO to IP and MIMC (USEPA 2009a). The 2009 UAO directs IP and MIMC to conduct an RI/FS for the SJRWP Site.

This document satisfies the requirement of the Statement of Work in the UAO for the submittal of a FS Report following receipt of USEPA approval of the Final RI Report (Integral and Anchor QEA 2013). The RI Report was conditionally approved by USEPA on April 4, 2013, and the Final RI Report was submitted to USEPA on May 17, 2013. The FS Report will ultimately lead to a proposed remedial action plan for the SJRWP Site (Proposed Plan). The Proposed Plan will be the subject of public comment and once finalized and will be incorporated into a USEPA Record of Decision (ROD) for the SJRWP Site.

The UAO describes a basic history of the SJRWP Site, but it addresses only the impoundments located on the north side of Interstate Highway 10 (I-10), referred to as the Northern Impoundments. USEPA subsequently required investigation of soil and groundwater in an area to the south of I-10, or "Soil Investigation Area 4" citing historical documents indicating possible waste disposal activities in that area (Figure 1-2). The area of investigation south of I-10 ultimately also included areas adjacent to Soil Investigation Area 4, at locations to the south and west of it, where USEPA required additional soil and groundwater samples.

A time critical removal action (TCRA) was completed in July 2011 in the Northern Impoundments, pursuant to an Administrative Settlement Agreement and Order on Consent for Removal Action: CERCLA Docket No. 06-12-10 (AOC) (USEPA 2010a). The TCRA stabilized and isolated pulp waste and sediments within the original 1966 perimeter berm of the Northern Impoundments to prevent any releases of dioxins and furans and other chemicals of potential concern (COPCs) to the environment (Anchor QEA 2011, 2012a). More information about the TCRA is provided in Section 2.5.3.

2 SETTING

This section provides a summary of information gathered concerning physical, chemical, and biological conditions within the USEPA's Preliminary Site Perimeter. This information is intended to provide the reader with an understanding of the SJRWP Site and the human actions, natural processes, and physical properties that may influence the nature and extent of chemicals of concern (COCs) within the USEPA's Preliminary Site Perimeter, and that may influence evaluation of remedial alternatives presented in Sections 4 through 6 of this report. A more comprehensive physical and biological description, as well as more detailed history of the area within the USEPA's Preliminary Site Perimeter, its environmental setting, and land uses are provided in the RI Report (Integral and Anchor QEA 2013).

2.1 Location and History

USEPA's Preliminary Site Perimeter includes several waste impoundments within the estuarine section of the San Jacinto River, as well as surrounding in-water and floodplains in the upland areas. The impoundments are located on the western side of the San Jacinto River, north and south of I-10 (Figure 1-1). The area within the USEPA's Preliminary Site Perimeter is generally flat with very little noticeable topographic relief across most of the area.

The impoundments were built in the mid-1960s for disposal of paper mill wastes barged from the Champion Paper Inc. paper mill in Pasadena, Texas. These wastes are a source of dioxins and furans present within the USEPA's Preliminary Site Perimeter and have been targeted for remediation. Other sources of dioxins and furans within USEPA's Preliminary Site Perimeter, such as atmospheric inputs, industrial effluents, publicly owned treatment works, and stormwater runoff, are discussed in Section 2.5.4. Over time, a variety of actions occurring within and in the vicinity of the USEPA's Preliminary Site Perimeter resulted in actual or potential disturbances to the impoundments, and introduced other sources of dioxins and furans, as well as other COCs into the soils and sediments within the USEPA's Preliminary Site Perimeter.

Large scale groundwater extraction by others, resulting in regional subsidence of land in the vicinity of the SJRWP Site and resulted in exposure of the contents of the Northern Impoundments to surface waters. Dredging and sand mining by others within the river and marsh to the west and northwest of the Northern Impoundments through the 1990s and early 2000s may have contributed to the exposure. Historical documents indicate that dredging actions also occurred in the river in the vicinity of the upland sand separation area located to the west of the Northern Impoundments (Upland Sand Separation Area) (Figure 1-

2). In addition, barge maintenance and cleaning activities conducted on and adjacent to the Upland Sand Separation Area in the mid-1990s by Southwest Shipyards included generation and storage of unspecified hazardous materials and wastes, including residual spent blast sand, paint chips, and rust chips swept from vessels prior to painting, paint drip, and overspray (GW Services 1997).

The peninsula south of I-10 and the area of investigation south of I-10 were characterized by intense industrial activity in the 1980s based on review of historical aerial images (Integral and Anchor QEA 2013). Southwest Shipyards' activities also have impacted areas south of I-10, including the western shoreline of the peninsula south of I-10 (GW Services 1997). Most of the upland area south of I-10 is currently in industrial or commercial use by marine services companies, with some parcels currently unused.

A more detailed discussion of the SJRWP Site history is provided in Sections 5.1 and 6.1 of the RI Report (Integral and Anchor QEA 2013).

2.2 Land Use

The land use types in the area surrounding the USEPA's Preliminary Site Perimeter are shown in Figure 2-1. The land parcels closest to the USEPA's Preliminary Site Perimeter are predominantly commercial/industrial, followed by residential areas. Moving farther from the USEPA's Preliminary Site Perimeter, the amount of residential land use increases. Upstream of the USEPA's Preliminary Site Perimeter, land uses include industrial and municipal activities that may result in releases of dioxins and furans or other COPCs into the San Jacinto River. For example, as described in the RI Section 5.4, in addition to regional sources of dioxins and furans, there are surface water drainage channels through two chemical manufacturing facilities upstream of the Site (Integral and Anchor QEA 2013).

2.2.1 Recreational and Navigational Use

The RI Report presents information regarding recreational and navigational use of the river and the area within the USEPA's Preliminary Site Perimeter. An advisory (ADV-49[1]) regarding the consumption of fish and blue crab exists on the San Jacinto River, including the area within the USEPA's Preliminary Site Perimeter. Sections 3.3.1 and 3.7.3 of the RI Report (Integral and Anchor QEA 2013) discuss surface water use and fishing advisories. Although fishing was reported to have occurred prior to TCRA implementation, there have been no systematic studies of the amount and frequency of fishing that may have occurred

[1] http://www.dshs.state.tx.us/seafood/survey.shtm and http://www.tpwd.state.tx.us/regulations/outdoor-annual/fishing/general-rules-regulations/fish-consumption-bans-and-advisories.

within the USEPA's Preliminary Site Perimeter prior to the implementation of the TCRA. The completion of the TCRA resulted in reduced public access to the Northern Impoundment area. Perimeter fencing was installed and warning buoys and signs were placed around the TCRA Site. In addition, access to the TCRA Site via boat is currently constrained to the north, west, south, and southeast by industrial use and navigational hazards (i.e., submerged sand bars and shallow water).

The commercial and industrial navigational use of the waterway is generally restricted by shallow depths outside the prescribed channel, as well as other "foul areas" where unidentified hazards are likely to exist. There is no Federally authorized navigation channel in the portions of the river within the USEPA's Preliminary Site Perimeter, and vessel heights are limited in the vicinity of the TCRA Site due to clearance limits under the I-10 Bridge. Barge fleeting and mooring occurs in many areas within the USEPA's Preliminary Site Perimeter, including the San Jacinto River Fleet (SJRF) operations near the former Upland Sand Separation Area (Figure 1-2).

2.3 Biological Habitat

The USEPA's Preliminary Site Perimeter is located within a low gradient, tidal estuary near the confluence of the San Jacinto River and the Houston Ship Channel (HSC). The surrounding area includes Lynchburg Reservoir to the southeast and the Lost Lake sediment management area (SMA) west of Lynchburg Reservoir (Figure 2-2). The I-10 freeway reduces the connectivity of habitats in the natural areas to the north and south of the highway, and industrial land use has diminished the habitat value of the uplands and aquatic areas within the USEPA's Preliminary Site Perimeter.

Some upland natural habitat adjacent to the river within the USEPA's Preliminary Site Perimeter remains, consisting primarily of clay and sand that support a variety of forest community types including composites such as loblolly pine-sweetgum, loblolly pine-shortleaf pine, water oak-elm, pecan-elm, and willow oak-blackgum (TSHA 2009). It is reasonable to expect a suite of generalist terrestrial species that are not highly specialized in their habitat requirements and are adapted to moderate levels of disturbance (Integral 2013a). Such species could include reptiles and amphibians (e.g., snakes, turtles), birds (e.g., starlings, pigeons), and mammals common to semi-urban environments (e.g., rodents, raccoons, and coyotes).

Wildlife habitats within the northern portion of USEPA's Preliminary Site Perimeter include shallow and deep estuarine waters, and shoreline areas occupied by estuarine vegetation. A sandy intertidal zone is present along the shoreline throughout much of the USEPA's Preliminary Site Perimeter (Figure 2-2). The tidal portions of the river and upper Galveston

Bay provide rearing, spawning, and adult habitat for a variety of marine and estuarine fish and invertebrate species. Species known to occur in the vicinity of the USEPA's Preliminary Site Perimeter include: clams and oysters, blue crab (*Callinectes sapidus*), black drum (*Pagonius cromis*), southern flounder (*Paralichthys lethostigma*), hardhead (*Ariopsis afelis*) and blue catfish (*Ictalurus furcatus*), spotted sea trout (*Cynoscion nebulosis*), and grass shrimp (*Paleomonetes pugio*) (Gardiner et al. 2008; Usenko et al. 2009). An estimated 34-acres of estuarine and marine wetlands are found within the USEPA's Preliminary Site Perimeter (Integral and Anchor QEA 2013).

On the peninsula to the south of I-10, most of the upland is zoned for commercial or industrial use. Minimal habitat is present in the upland terrestrial area within the USEPA's Preliminary Site Perimeter. Demolition of former industrial facilities and current operations in support of barge fleeting and other industrial activities have created a denuded upland with a covering of crushed concrete and sand. The sandy shoreline of this area has scattered riprap, other metal debris, and piles of concrete fragments. The upland vegetation present on the peninsula south of I-10 is primarily low-lying grasses, with a few shrubs and trees adjacent to the shoreline.

A more detailed description of the local ecological system can be found in Section 3.8 of the RI Report (Integral and Anchor QEA 2013) and in Section 3.4 of the BERA (Integral 2013a).

2.4 Physical Description

2.4.1 Waterway Hydrodynamics

Water depths within the USEPA's Preliminary Site Perimeter range from relatively shallow in intertidal areas (3 feet or less) to relatively deep in the main channel of the river (about 30 feet). The typical tidal range in the river is about 1 to 2 feet, with neap and spring tide conditions corresponding to minimum and maximum tidal ranges, respectively. Tropical weather systems can have tremendous impacts on regional precipitation and hydrology along the Gulf Coast. Hurricane season runs from June 1 to November 30. Between 1851 and 2004, 25 hurricanes have made landfall along the north Texas Gulf Coast, seven of which were major (Category 3 to 5) storms. Tropical Storm Allison, which hit the Texas Gulf Coast on June 5 through 9, 2001, resulted in 5-day and 24-hour rainfall totals of 20 and 13 inches, respectively, in the Houston area, resulting in significant flooding. More recently, Hurricane Rita made landfall on September 23, 2005, between Sabine Pass, Texas, and Johnsons Bayou, Louisiana, as a Category 3 storm with winds at 115 mph and it continued on through parts of southeast Texas. The storm surge caused extensive damage along the Louisiana and extreme southeastern Texas coasts. On September 13, 2008, the eye of Hurricane Ike made landfall at the east end of Galveston Island and travelled north up Galveston Bay, along the east side of Houston. Ike made its landfall as a strong Category 2 hurricane, with Category 5-equivalent storm surge, and hurricane-force winds that extended 120 miles from the storm's center. Storms with strong winds from the north can cause water to be transported out of the Galveston Bay system, which can result in water levels that are much lower than low tide elevations.

Flow rates in the San Jacinto River in the vicinity of the Site are partially controlled by the Lake Houston dam, which is located about 16 river miles upstream of the northern impoundments. The average flow in the river is 2,200 cubic feet per second (cfs). Floods in the river occur primarily during tropical storms (e.g., hurricanes) or intense thunder storms. Extreme flood events have flow rates of 200,000 cfs or greater. Floods can cause water surface elevations to increase by 10 to 20 feet or more (relative to average flow conditions).

Between October 14 and October 21, 1994, heavy rainfall occurred in a 38-county area of southeast Texas. The San Jacinto river basin received 15 to 20 inches of rain during this week-long period. One of the largest measurements of streamflow ever obtained in Texas, 356,000 cubic feet per second, was made on the San Jacinto River near Sheldon on October 19 at a stage of 27 feet. During the measurement, velocities of water that exceeded 15 feet/second (about 10 miles per hour) were observed (USGS, 1995). Another storm occurring in 1940 had a river stage height of 31.50 feet at the same Sheldon location.

The 100-year flood, which is defined as the peak stream flow having a 1 percent chance of being equaled or exceeded in any given year, was equaled at 1 and exceeded at 18 of 43 stations monitoring the area. For those stations where the 100-year-flood was exceeded, the flood was from 1.1 to 2.9 times the 100-year-flood (NTSB 1996).

The 1994 flooding caused major soil erosion and created water channels outside of the San Jacinto River bed. This flooding caused eight pipelines to rupture and 29 others were undermined at river crossings and in new channels created in the flood plain outside of the San Jacinto River boundaries. The largest new channel was cut through the Banana Bend oxbow just west of the Rio Villa Park subdivision, about 2 ½ miles northwest of the Site. This new channel was approximately 510-feet wide and 15-feet deep. A second major channel cut through Banana Bend just north of the channel through the oxbow. Both of these new channels were cut through areas where sand mining had been done before as is the case in the vicinity of the Site. Sonar tests in a 130-foot section south of the I-10 Bridge located adjacent to the Site found about 10 to 12-feet of erosion from the bottom of the river bed. The flooding forced over 14,000 people to evacuate their homes. (NTSB, 1996). The

Houston Chronicle in early November listed 22 flood-related deaths and 15,775 homes damaged, including 3,069 destroyed and 6,560 requiring major repairs (USGS, 1995).

The San Jacinto River within the USEPA's Preliminary Site Perimeter is a well-mixed estuarine system. Flow rates and freshwater inputs in the river in the vicinity of the USEPA's Preliminary Site Perimeter are partially controlled by the Lake Houston dam, upstream of the USEPA's Preliminary Site Perimeter. Salinity ranges from 2 to 20 parts per thousand, but may approach 0 parts per thousand during flood conditions (Integral and Anchor QEA 2013).

During low-flow conditions when current velocities were dominated by tidal effects, maximum velocities were measured to be about 1 foot per second, with typical velocities of 0.5 feet per second or less during most of the tidal cycle (Integral and Anchor QEA 2013).

2.4.2 Riverbed Characteristics and Sediment Transport

A detailed evaluation and analysis of the riverbed and sediment transport processes within the USEPA's Preliminary Site Perimeter was presented in the RI Report, as well as in the Chemical Fate and Transport Modeling Report (Anchor QEA 2012c).

The nature of the sediment bed affects sediment transport processes, as well as chemical distributions. As described in the RI Report, the sediment bed within the USEPA's Preliminary Site Perimeter is composed of approximately 80 percent cohesive (i.e., muddy) and 20 percent non-cohesive (i.e., sandy) sediments (Integral and Anchor QEA 2013). Erosion rate data of cohesive sediment collected in the San Jacinto River indicate that the erodibility of bed sediment decreases with increasing depth in bed (Anchor QEA 2012c). The primary source of sediment to the San Jacinto River and within the USEPA's Preliminary Site Perimeter is suspended sediment in surface waters discharged from the Lake Houston Dam. The average annual sediment load at the dam is approximately 381,000 metric tons (Anchor QEA 2012c).

Sediment stability within the USEPA's Preliminary Site Perimeter may be affected by human activities and natural processes as discussed in the RI Report (Integral and Anchor QEA 2013):

- Near-bed velocities generated by episodes of propeller wash are expected to be higher than those due to tidal and riverine currents in areas of the river that are subjected to vessel operations (e.g., at the SJRF operations area and within the navigation channel). Bed-shear stress due to vessel operations is expected to be higher than bed-shear stress due to natural forces and may have the potential to disturb sediments in these vessel operation areas. Near and above the Armored Cap where vessel access is constrained (Section 2.2.1), natural forces are expected to provide the dominant bed-shear stress.

- Although the rate of subsidence has decreased during the last 35 to 40 years, due to controls on groundwater usage within Harris County, the effect of subsidence in the future, if it occurs on bed sediments in the San Jacinto River, will be to reduce the potential for erosion. Subsidence lowers the sediment bed elevation, and thus, increases water depth and decreases current velocities, which in turn reduces potential for bed erosion.

- Sea level rise is projected to continue at a rate of approximately 2 to 3 millimeters per year (mm/year) during the next century, with a total increase in sea level of about 0.5 to 2 feet by the year 2100 (Anchor QEA 2012c). The effect of sea level rise on bed sediment in the San Jacinto River will be to reduce the potential for erosion because rising sea level increases water depths, which generally decreases current velocities.

The stability of the sediment bed is an important factor for considering natural recovery processes and in evaluating remedial alternatives for deeply buried deposits of sediment that might exceed the identified PRGs (discussed in Section 3.1) for the areas within the USEPA's Preliminary Site Perimeter. Evaluation of the radioisotope coring data from within the USEPA's Preliminary Site Perimeter indicates the net sedimentation rate (NSR) is approximately 0.4 to 3.9 centimeters per year (cm/year) in depositional areas (Anchor QEA 2012c). The effects of changes in sediment load from upstream sources on long-term sedimentation were evaluated during the modeling study and are discussed in the Chemical Fate and Transport Modeling Report (Anchor QEA 2012c), as well as in Appendix A of this report. Sedimentation rates may change with time if land use restrictions, discharge limitations, or other regulatory developments related to stormwater discharge are implemented within the San Jacinto River basin; however, sediment loads from sources located downstream of Lake Houston dam are minimal compared to the load at the dam (Anchor QEA 2012c). Thus, any potential decreases in loads downstream of the dam in the future will have negligible effect on long-term sedimentation within the USEPA's Preliminary Site Perimeter.

2.5 Nature and Extent of COCs

The RI Report (Integral and Anchor QEA 2013) contains an in-depth discussion of the process involved to identify COCs within the USEPA's Preliminary Site Perimeter, and the nature and extent of COCs north of I-10 (RI Report Section 5.2) and the area of investigation south of I-10 (RI Report Section 6.2). Based on sediment data and the results of the BERA and BHHRA, dioxins and furans were identified as the indicator chemical group for the purposes of the RI/FS (see Appendix C of the RI/FS Work Plan; COPC Technical Memorandum [Integral 2011], and the RAM [Anchor QEA 2012b]). This section discusses the nature and extent of COCs focusing specifically on this chemical group.

2.5.1 North of I-10

Under baseline conditions, the highest 2,3,7,8-tetrachlorinated dibenzo-*p*-dioxin toxic equivalents (TEQ) concentrations calculated for mammalian receptors using dioxins and furans only ($TEQ_{DF,M}$) in sediment were found in the area of the Northern Impoundments, which corresponds to the area capped by the TCRA. Outside of the TCRA Site, $TEQ_{DF,M}$ concentrations in sediment and soils are significantly lower. Figure 2-3 presents the $TEQ_{DF,M}$ concentrations in surface sediment. As presented, concentrations for each sample are color-coded based on powers of 10 to facilitate identifying areas of similar concentration. Figure 2-4 presents $TEQ_{DF,M}$ concentrations in samples collected from sediment cores. The $TEQ_{DF,M}$ concentrations in sediment are discussed in the context of the PRGs in Section 3.1.

The RI Report also examined concentrations of polychlorinated biphenyls (PCBs) and mercury in the TCRA Site soils/sediments. The source evaluation of the area north of I-10 and surrounding aquatic environments presented in Section 5.4 of the RI Report concluded that the PCB concentrations in sediments within the USEPA's Preliminary Site Perimeter, but outside the Northern Impoundments are not highly elevated relative to areas outside of the USEPA's Preliminary Site Perimeter and contribute very little dioxin-like toxicity to the sediment. In addition, because mercury concentrations in the soils on the Upland Sand Separation Area (as shown in Figure 1-2), are higher than they are in the wastes within the Northern Impoundments, the wastes within the Northern Impoundments may not the primary source of mercury in the aquatic environment under investigation.

2.5.2 Area of Investigation South of I-10

Available historical documentation indicates that some of the wastes deposited within Soil Investigation Area 4 may have originated from the Champion Paper Inc. paper mill (TDH 1966). As noted in the RI Report, the BHHRA for the area of investigation on the peninsula south of I-10 found no health risks in surface soil to hypothetical trespassers and hypothetical commercial workers above the thresholds considered acceptable by USEPA. For hypothetical future construction workers, exposure scenarios for three individual core locations (each assumed to be representative of a potential building site, and assuming excavation or other activities that would disturb the soil) resulted in noncancer and dioxin cancer hazard indices greater than 1. Dioxins and furans, as $TEQ_{DF,M}$ were identified as COCs for the hypothetical future construction worker, based on hypothetical future exposures to the upper 10-feet of soil. At the request of USEPA, risk to a hypothetical future construction worker who could be exposed to the upper 5 feet of soil only was also evaluated, as described in Section 3.1. A full description of the risk evaluation assumptions, uncertainties, and data evaluation is provided in the BHHRA (Integral 2013b).

The BERA for the area of investigation south of I-10 identified low risks to terrestrial bird populations from lead and zinc. Lead and zinc were therefore identified as COCs. Soil PRGs were not developed for these metals because of uncertainties associated with the exposure modeling that likely overestimated exposures, and because these two metals are not associated with paper mill waste, but are likely present due to other industrial activities within the area of investigation on the peninsula south of I-10.

Figure 2-5 presents $TEQ_{DF,M}$ concentrations in surface and subsurface soil in the area south of I-10. The data are discussed relative to the PRG for a hypothetical future construction worker and a hypothetical future commercial worker in Section 3.1. The exposure scenario for the hypothetical future construction worker receptor assumes exposure to a depth-weighted average of $TEQ_{DF,M}$ concentrations throughout a 10-foot soil depth, but the most elevated $TEQ_{DF,M}$ concentrations are found in samples taken at locations several feet below grade. As discussed in the BHHRA and the RI Report, several feet of relatively clean soil isolates the soil with the highest $TEQ_{DF,M}$ concentrations from potential receptors at the surface.

2.5.3 Prior Actions at the SJRWP Site

As discussed in Section 1.2, a TCRA was implemented, pursuant to an AOC, to stabilize and isolate paper mill waste and sediments within the original 1966 perimeter berm of the Northern Impoundments (Anchor QEA 2011; USEPA 2012c). As presented in the Action Memorandum (USEPA 2010a, Appendix A) for the TCRA, the following removal action objectives for the TCRA were identified:

- Stabilize waste pits to withstand forces sustained by the river.
  - The barrier design and construction must be structurally sufficient to withstand forces sustained by the river including any future erosion and be structurally sound for a number of years until a final remedy is designed and implemented (USEPA 2010a).

  - Technologies used to withstand forces sustained by the river must be structurally sufficient to withstand a storm event with a return period of 100-years until the nature and extent of contamination for the Site is determined and a final remedy is implemented.

- Prevent direct human contact with the waste materials (USEPA 2010a, Appendix A, IV.A.1; Page 9; first paragraph).

- Prevent benthic contact with the waste materials (USEPA 2010a, Appendix A, III.B).

- Ensure that the "actions are consistent with any long-term remediation strategies that may be developed for the Site" (USEPA 2010a, Appendix A, V.A.2).

The TCRA included construction of an armored isolation cap (Armored Cap), completed in July 2011, that was designed in accordance with U.S. Army Corps of Engineers (USACE) and USEPA guidelines. During the design of the TCRA, the area within the original 1966 perimeter of the Northern Impoundments was divided into three distinct areas: 1) the Eastern Cell; 2) the Western Cell; and 3) the Northwestern Area (Figure 2-6). In general, the TCRA design included an armor rock cap placed atop a geotextile bedding layer in all but the Northwestern Area, where an aggregate cap was constructed. Additionally, the Western Cell received treatment through stabilization and solidification (S/S) of approximately 6,000 cubic yards (cy) of material in the upper 3 feet of material over a 1.2 acre portion of the area, and a geomembrane cover layer prior to armor rock installation. The Armored Cap is discussed further in Section 4 relative to the remedial alternatives, and shown in the figures from that Section. In addition to capping the Northern Impoundments, the TCRA upland perimeter was fenced and signage was installed to prevent unauthorized access to the TCRA Site. A description of the TCRA implementation is provided in the Removal Action Completion Report (RACR) (USEPA 2012c). Costs for design and implementation of the TCRA were more than $9 million.

The Armored Cap has been subject to ongoing inspections, monitoring, and maintenance, consistent with USACE and USEPA guidelines and the agency-approved Operations, Monitoring, and Maintenance (OMM) Plan (Appendix N of the RACR, Anchor QEA 2012a). Three separate post-construction survey and monitoring events (conducted in September 2011, January 2012, and April 2012) confirmed the integrity of the Armored Cap. During the next inspection, in July 2012, an area along the western berm slope was noted to have areas where cap armor materials had moved down the slope, uncovering a small area of the geotextile layer (approximately 200 square feet, or 0.03 percent of the Armored Cap footprint). There was no exposure of underlying materials or release of hazardous substances associated with this temporary condition. Consistent with the agency-approved OMM Plan, the Respondents implemented approved maintenance measures that involved grading specific locations to an overall flatter condition by placing additional armor rock over the cap surface in those locations. These maintenance activities were completed in July 2012 and were documented in a completion report that was submitted to USEPA (Anchor QEA 2012d). Additional maintenance was performed in January 2013, when additional armor stone was placed in other cap areas. This work was completed and documented in a completion report prepared for USEPA (Anchor QEA 2013b, Appendix B). (As discussed in more detail in Section 4.1.3, sediment caps commonly require localized maintenance during the initial post-construction period, and USACE and USEPA guidance identifies ongoing inspection and maintenance of the type required by the OMM Plan as an integral component in ensuring that sediment caps remain protective over the long-term.) Subsequent inspection and monitoring has continued to verify the integrity of the Armored Cap.

During the post-construction period, the Respondents (Anchor QEA 2013a) and USEPA, in coordination with USACE (USACE 2013), conducted separate evaluations of the Armored Cap design and construction. The USACE report conclusions are quoted as follows:

1. *Parameterization of the stone size equation. The inputs to the [stone size] equation were not provided. The design velocity from the hydrodynamic model may not account adequately for the slope changes due to limitations in spatial resolution. The factor of safety may not have [been] adequate for the uncertainties in construction, slopes, material gradation, waves, non-uniform flow, flow constrictions and overtopping.*[3]

2. *Slope. The slope of the face of the berm just below the crown was much steeper than the design slope and was not modified prior to capping. For the non-uniform recycled concrete used for Armor Cap B/C, the design slope should have been [1 vertical to 3 horizontal] 1V:3H or flatter to prevent excessive displacement and loss of gravel and sand sized particles.*[4]

3. *Armor cap material gradation. The uniformity of the armor cap material was not specified. The material specifications allowed too much gravel and sand sized particles to be used, which could be eroded from the cap because they did not meet internal stability and retention criteria. Greater uniformity of*

[3] Note that these input parameters have been provided to USEPA and USACE.

[4] Note that the enhancements completed in January 2014 used natural stone material, placed at the USACE recommended 1V:3H slope.

the armor cap is preferable in the high energy regimes of the cap, particularly the southwestern corner of the berm.[5]

4. *Repair should ensure that the final surface throughout the repair area and adjacent areas has a slope of 1V:3H or flatter.*

In accordance with these conclusions and recommendations, the Respondents conducted additional cap enhancement work during January 2014. A description of the completed work was provided in the TCRA Cap Enhancement Completion Report (Anchor QEA 2014). This enhancement work was conducted using stone that was larger than the minimum stone size recommended by USACE, therefore providing an even more stable and protective cap configuration and exceeding design criteria specified in USACE and USEPA sediment capping design guidance (USACE 1998).

In January 2013 five areas in the Eastern Cell of the cap with less than the required armor cover thickness and/or exposed geotextile were identified. In one of those areas there is a need for placement of geotextile fabric in addition to armor stone. The cause of these areas of deficient cap cover is unknown. These areas were repaired in January 2013 with the addition of additional stone and geotextile.

On December 9 and 10, 2015, EPA performed an underwater inspection that identified an area of deficient thickness and/or missing armor cover resulting in exposure of the underlying paper mill waste material to the San Jacinto River. The deficient area is located on the northwestern section of the armored cap where no geotextile was installed. The area is irregularly shaped with dimensions of approximately 22 feet by 25 feet. Armored rock cover was still present, but coverage was not complete nor was there adequate thickness. The cause of the deficient area is unknown. Sediment sampling completed in December 2015 identified dioxin/furan in the exposed sediment as high as 43,700 ng/kg TEQ. Maintenance activities to place geotextile and additional rock cover over and extending beyond the deficient area began on December 29, 2015, and were completed on January 4, 2016.

On February 24, 2016, during an extremely low tide, a visual inspection of the cap was performed. A large majority of the Eastern Cell was exposed during this abnormally low tide event. Five small areas (approximately 1 foot by 3 feet at the largest areas) of exposed geotextile with no rock cover were observed in the central part of the Eastern Cell where the

[5] Note that Armor Rock C, as described in the TCRA RAWP (Anchor QEA 2011), was considered sufficient by USACE for cap enhancement in their report. Armor Rock D, which is even larger than Armor Rock C, was used for the enhancement work completed in January 2014.

cap should have had a one-foot thickness minimum. The cause of these deficient rock areas is unknown, although some of the areas may have been geotextile overlap portions associated with the cap construction. During March 2016 probing of the entire Eastern Cell of the cap to check thickness was completed and identified additional areas of deficient armor cover thickness and/or exposed geotextile. Rock was added to all of these areas in the Eastern Cell in March 2016 to achieve a minimum thickness of one foot.

2.5.3.1 Effectiveness of the Time Critical Removal Action

The post-TCRA evaluation confirms that the TCRA's implementation has reduced potential risks from dioxins and furans associated with baseline conditions. The following sections discuss effects of TCRA implementation on sediment, water, and tissue.

2.5.3.1.1 Sediment

Implementation of the TCRA has eliminated, with one known exception, the potential transport of waste associated COCs from the Northern Impoundments. The effect of the TCRA on overall sediment quality within the USEPA's Preliminary Site Perimeter was evaluated in the RAM by performing a "hilltopping" evaluation comparing the surface-weighted average concentration (SWAC) of $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter for various prospective remedial action levels (RALs), including SWACs before TCRA implementation and following TCRA completion. As documented in the RAM, the $TEQ_{DF,M}$ SWAC was reduced by more than 80 percent by implementing the TCRA. In addition, on-going natural recovery continues to reduce surface sediment concentrations outside of the TCRA Site, as indicated by the long-term chemical fate model simulations presented in Appendix A. However, the simulations did not consider the impact of a dioxin release that may result for a future extreme storm or hurricane, nor the impacts of a barge strike that may breach the cap.

2.5.3.1.2 Water

Sampling of surface water and porewater with solid phase micro-extraction (SPME) fibers was conducted after construction of the Armored Cap was completed. The sampling indicated that 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and 2,3,7,8-tetrachlorodibenzofuran (TCDF) were not present in surface water over the Armored Cap. Data generated from this porewater assessment support evaluation of remedial alternatives that incorporate the Armored Cap into the final remedy.

The chemical fate and transport modeling presented in Appendix A was used to evaluate the potential for reductions in surface water concentrations associated with implementation of the TCRA. The model results showed that as a result of the Armored Cap, annual average concentration estimates of 2,3,7,8-TCDD predicted by the model in surface water have decreased by approximately 85 percent in the area of the TCRA Site and by 40 percent when averaged over the USEPA's Preliminary Site Perimeter. As discussed in Appendix A, the concentrations predicted by the model for post-TCRA conditions reflect dioxin/furan inputs associated with a number of sources, including transport from upstream, atmospheric deposition, surface runoff, point discharges (industrial and municipal treatment plant effluents), and fluxes from surface sediment outside the Armored Cap.

2.5.3.1.3 Tissue

Upon completion of the TCRA construction in July 2011, sediments in the TCRA Site were rendered inaccessible for direct contact by humans, benthos, fish, and aquatic dependent wildlife. The completion of TCRA construction therefore would be expected to lead to reductions in tissue concentrations in catfish and clams within the USEPA's Preliminary Site Perimeter.

2.5.4 Sources of COCs

The chemical fate and transport modeling, discussed in Section 2.5.5 and Appendix A, concluded that ongoing deposition of sediment within the USEPA's Preliminary Site Perimeter may continue to reduce concentrations of dioxins and furans in sediment. However, deposition rates are low in most areas, particularly shallow areas. Further, changes in the river geometry as a result of extreme erosion similar to that which was documented during the 1994 flood may prevent the predicted deposition from occurring. As noted in the RI Report, a number of historical and current sources of dioxins, furans, and other COCs remain as ongoing contributors to COC concentrations present within the USEPA's Preliminary Site Perimeter.

The chemical analyses of groundwater, soils, and sediments presented in both the Preliminary Site Characterization Report (PSCR; Integral and Anchor QEA 2012) and the RI Report demonstrated that other regional sources – such as atmospheric inputs, industrial effluents, publicly owned treatment works, and stormwater runoff – contribute dioxins and furans and other COCs (metals, and PCBs) found in the TCRA Site area and surrounding aquatic environment. In the area of investigation south of I-10, historical and ongoing industrial marine services are known to contribute chemicals, including COCs for ecological receptors to soils.

The "unmixing" evaluations based on fingerprinting of dioxin and furan mixtures in soil and sediment samples described in the RI Report demonstrate that there are sources other than paper mill wastes of dioxins and furans in sediment and soils within USEPA's Preliminary Site Perimeter, including within the Northern Impoundments and Soil Investigation Area 4. Sediments within the USEPA's Preliminary Site Perimeter contain a specific distribution of individual dioxin and furan congeners that is likely attributable to the urban background and specific regional sources surrounding the USEPA's Preliminary Site Perimeter.

In the peninsula south of I-10, soils and subsurface soils contain dioxins and furans from a mixture of sources including paper mill wastes, as well as other background or site-specific sources. The unmixing analysis for soils collected from the area of investigation south of I-10 indicates that there are three distinctive dioxin and furan source types contributing to the presence of dioxins and furans in soils sampled south of I-10 including one that resembles paper mill wastes, one that resembles background dioxin and furan sources, and a third mixture unique to this area. The dioxin and furan mixture towards the southern end of Soil Investigation Area 4 in shallower soils is consistent with the fingerprint characteristic of paper mill wastes, based on fingerprints of samples collected from within the impoundments north of I-10. In deeper soils at the southern and northern ends of the area of investigation on the peninsula south of I-10, the dioxin and furan mixture describes a different source type that is not observed elsewhere within the USEPA's Preliminary Site Perimeter, and does not appear to match apparent source types in other soils or sediment samples collected from within the USEPA's Preliminary Site Perimeter nor any known anthropogenic source pattern in the USEPA Dioxin Reassessment database (USEPA 2004). The general spatial distribution of sources that differ from the paper mill wastes in soils suggests that dioxin and furan containing material was deposited into, or on the peninsula south of I-10, at a point in time prior to disposal of paper mill wastes. Finally, outside of Soil Investigation Area 4, the dioxin and furan mixtures are generally dominated by a fingerprint consistent with general urban background sources. The unmixing analysis demonstrates that paper mill wastes are mostly confined to the area within USEPA's estimated perimeter of the impoundment. Spatial patterns of dioxins and furans and other chemicals within subsurface soils in the area of investigation south of I-10, as well as waste materials (such as paint chips, construction debris, plastics, and asphalt shingles) and chemicals not associated with paper mill wastes, also support the conclusion that wastes other than paper mill wastes have contributed to the presence of dioxins and furans in soils in the area of investigation south of I-10 (see RI Report Section 6.6).

2.5.5 Chemical Fate and Transport

Section 5.6 of the RI Report contains a summary of the chemical fate and transport processes affecting the concentrations of dioxins and furans within the USEPA's Preliminary Site Perimeter. The most significant points of this discussion are summarized below:

- Sediment-water interactions – Dioxins and furans are hydrophobic and preferentially bind to particulate matter (PM). Particulate-associated dioxins and furans within the sediment bed enter the water column through sediment deposition and erosion processes described in Section 2.5. Deposition of sediments with low concentrations of chemicals may support natural recovery.

- Partitioning and dissolved phase flux – Because dioxins and furans are hydrophobic, they will be present primarily in particulate form, and their fate is therefore determined largely by sediment transport processes. Dioxins and furans within the sediment matrix include dissolved-phase dioxins and furans in porewater through partitioning processes, which can result in a transfer of dissolved-phase mass to the water column under certain conditions.

- Transport in the water column – Dioxins and furans present in the water column in any phase are transported by surface water currents, which are affected by hydrodynamic processes within the larger San Jacinto River.

- External sources – Publicly owned treatment plant outfalls, other point-source discharges, stormwater runoff and atmospheric deposition are all sources of dioxins and furans within USEPA's Preliminary Site Perimeter. As documented in the RI Report, groundwater is not a source of dioxins or furans to the San Jacinto River. The modeling described in Appendix A includes contributions from these external sources.

A detailed description of the modeling is provided in the Chemical Fate and Transport Modeling Report (Anchor QEA 2012c), and supporting documentation. More detailed discussions of dioxin and furan bioaccumulation in aquatic biota are presented in the Technical Memorandum on Bioaccumulation Modeling (Integral 2010), Section 5.6 of the RI Report (Integral and Anchor QEA 2013), and in the BERA (Integral 2013a).

2.5.5.1 Bioaccumulation

The data analyses and literature review presented in the Technical Memorandum on Bioaccumulation Modeling (Integral 2010), including evaluation of region-specific multivariate datasets, indicates that the majority of dioxin and furan congeners do not consistently bioaccumulate in fish or invertebrate tissue. This is due to biological controls on uptake and excretion in both fish and invertebrates (Integral 2010). As a result, systematic predictions of bioaccumulation from concentrations of dioxins and furans in abiotic media (both sediment and water) are only possible for tetrachlorinated congeners. However, even these correlations are weak, and are associated with high uncertainty (Integral 2010). Analyses presented in the BERA (Integral 2013a) indicated that concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF in the tissues of clams and killifish (which have limited spatial movements) were higher in those clams and killifish taken in proximity to the Northern Impoundments (prior to TCRA construction). Consistent with the literature (USEPA 2009b), benthic species (clams and catfish) had higher concentrations of dioxins and furans than predatory fish species, suggesting that concentrations of dioxins and furans are not predicted by position in the food chain, but are accumulated more as a function of proximity to sediment in which dioxins and furans are present. The fact that concentrations in clam tissue correlate reasonably well with concentrations in sediments adjacent to where they were collected reinforces the "proximity hypothesis" in support of the conceptual framework for bioaccumulation of dioxin and furans, outlined in the Technical Memorandum on Bioaccumulation Modeling (Integral 2010).

2.5.6 Fate and Transport Modeling

A comprehensive fate and transport model was developed to support the RI/FS. The fate and transport model development and calibration is provided in the Chemical Fate and Transport Modeling Study Report (Anchor QEA 2012c). The primary goal of the modeling study was to simulate physical and chemical processes that are controlling chemical fate and transport of selected dioxins and furans within the aquatic environment of the area within the USEPA's Preliminary Site Perimeter. Specifically, the primary objectives of the chemical fate and transport analysis were threefold:

- Develop a CSM for sediment transport and chemical fate and transport.
- Develop and apply quantitative methods (i.e., computer models) that can be used to evaluate the effectiveness of various remedial alternatives during the FS.
- Address specific questions about sediment transport and chemical fate and transport processes within the USEPA's Preliminary Site Perimeter.

The mathematical modeling framework that was applied consists of three models that were linked together: hydrodynamic, sediment transport, and chemical fate and transport. These models were developed, calibrated, and tested (as described in Anchor QEA 2012c) and together form a quantitative framework that can be used as a management tool that can help guide remedial decision making. The calibration and validation of the model framework indicates that it can simulate hydrodynamics, sediment transport, and chemical fate and transport within the Model Study Area (i.e., San Jacinto River from Lake Houston Dam to the confluence with the HSC) with sufficient accuracy to support its use to make relative comparisons among remedial alternatives in the FS Report. The above notwithstanding, the models do have uncertainty due to data limitations, particularly for dioxins and furans in surface water.

Overall, the modeling framework provides a useful management tool to develop future predictions of dioxin and furan concentrations in sediment and surface water within the USEPA's Preliminary Site Perimeter. Specific FS model applications, which are presented in Appendix A, included the following:

- Long-term simulations of post-TCRA future conditions (i.e., starting from current conditions, which include the presence of the Armored Cap over the TCRA Site) were conducted. These simulations provide estimates of rates of natural recovery (i.e., reductions in estimated water column and surface sediment dioxin and furan concentrations over time) in various portions of the Model Study Area, which are representative of conditions anticipated for Alternatives 1N through 3N described in Section 4 below.

- In addition, long-term simulations of alternatives containing in-water sediment remediation (i.e., Alternatives 4N through 6N described in Section 4 below) were also conducted. Future sediment and water column dioxin and furan concentrations from these simulations were used to evaluate potential short- and long-term impacts associated with the construction activities (i.e., sediment resuspension and release during sediment remediation and effects of dredge residuals).

Results from the fate and transport modeling conducted to support the alternatives analysis are described in detail in Appendix A to this FS Report. Appendix A also includes a description of model uncertainty analyses that were conducted to develop uncertainty bounds around its predictions, as well as a summary of certain sensitivity analyses that were performed with the hydrodynamic and sediment transport models at the request of USEPA in its letter approving the draft final report for the modeling study.

3 BASIS FOR REMEDIAL ACTION

The basis for undertaking remedial action is to address the potential risks associated with the presence of dioxin and furan containing sediment resulting from historical paper mill waste disposal in the Northern Impoundments, as well paper mill wastes present in the Soil Investigation Area 4, south of I-10. This section discusses the development of PRGs, reviews the RAOs established by USEPA for the area within the USEPA's Preliminary Site Perimeter, and reviews the Applicable or Relevant and Appropriate Requirements (ARARs) that have been identified in previous documents.

3.1 Recommended Protective Concentration Levels

The RAOs are focused on remedial measures applicable to sediments and soils within the USEPA's Preliminary Site Perimeter to reduce potential exposure pathways to humans and ecological receptors. Therefore, the PRGs utilized in the development of remedial alternatives are those developed for soils and sediments. All of the PRGs used in the evaluation of alternatives were approved by USEPA, and are based on $TEQ_{DF,M}$ concentrations that are protective of human health, based on the Reasonable Maximum Exposure (RME) scenario for the subject hypothetical receptors.

PRGs were developed as described in the RI Report, the May 14, 2013 letter from Anchor QEA to USEPA Region 6 (Anchor QEA 2013), and the January 16, 2015, letter from Anchor QEA to USEPA Region 6 (Anchor QEA 2015). The PRGs for the hypothetical recreational visitor and hypothetical future construction worker were developed using methodologies contained in USEPA guidance documents and presented in the May 14, 2013 letter and the January 16, 2015, letter. The development of PRGs considered all potential exposure pathways associated with hypothetical receptor exposure scenarios approved by USEPA, including reasonably anticipated future uses of specific areas within the USEPA's Preliminary Site Perimeter, and all COCs for each medium. Based on consideration of reasonable potential future uses within the USEPA's Preliminary Site Perimeter, four PRGs were developed for use in the FS Report for evaluation of the remedial alternatives of sediments and soils. The reasonable potential future users within the USEPA's Preliminary Site Perimeter used in the development of alternatives include hypothetical recreational fisher and hypothetical recreational visitor for sediments, and hypothetical construction and hypothetical commercial workers for soils. Exposure assumptions for hypothetical subsistence fisher scenarios provided in the RI Report are not consistent with the anticipated future uses within USEPA's Preliminary Site Perimeter, so the PRG for that scenario was not used in the development of alternatives.

PRGs were also developed for total PCBs and arsenic for soils and sediments, and for total PCBs, arsenic, and mercury in tissue in the RI Report. Cancer-based PRGs for total PCBs and arsenic were developed at the request of USEPA. However, the estimated lifetime cancer risks for all receptors from exposures to total PCBs and arsenic did not exceed the upper bound of the cancer risk of $1x10^{-4}$ that USEPA regards as acceptable, as is outlined in the Exposure Assessment Memorandum (EAM) and the BHHRA. Also, an evaluation of PCBs and mercury concentrations in soils/sediments was presented in the RI Report, and it was concluded that the PCB concentrations are not highly elevated and contribute very little dioxin-like toxicity. Moreover, concentrations of each dioxin-like PCB congener in sediments were either correlated with concentrations of TCDD and TCDF (Integral 2011), indicating that remediation for dioxins and furans will also address these PCBs (Anchor QEA and Integral 2010a, Appendix C), or were generally below detection limits. The elevated mercury concentrations in the soils on the Upland Sand Separation Area are higher than in the wastes within the Northern Impoundments, indicating that elevated mercury concentrations are not related to paper mill waste. Therefore, the evaluation of remedial alternatives is focused on the PRGs for $TEQ_{DF,M}$.

The $TEQ_{DF,M}$ PRG for sediment outside the footprint of the Armored Cap is based on exposure to dioxins and furans by a hypothetical recreational visitor, as evaluated in the BHHRA. For a noncancer hazard quotient equal to 1[2], the $TEQ_{DF,M}$ concentration in sediment for this PRG is 200 nanograms per kilogram (ng/kg) (Anchor QEA 2015). Although the PRG for the hypothetical recreational fisher would also be appropriate, the PRG for the hypothetical recreational visitor is more conservative. Figures 3-1 and 3-2 present $TEQ_{DF,M}$ concentrations in surface and subsurface sediment, respectively, outside the footprint of the Armored Cap. The measured $TEQ_{DF,M}$ concentrations in sediments exceeded this PRG in only one location, northwest of the TCRA Site near the Upland Sand Separation Area, in two subsurface sample intervals at depths of 4 and 6 feet below ground surface.

The PRG for soil/sediment within the footprint of the TCRA is based on the reasonable future use of this area, which is industrial or commercial. A PRG was derived as presented in the January 16, 2015 letter (Anchor QEA 2015) for a hypothetical future outdoor commercial worker assumed to be exposed to soil/sediment in the TCRA footprint. For a noncancer hazard quotient equal to 1, the PRG as a $TEQ_{DF,M}$ concentration in soil/sediment is 750 ng/kg. Figures 3-3 and 3-4 present $TEQ_{DF,M}$ concentrations in surface and subsurface sediment, respectively, within the footprint of the Armored Cap relative to this PRG.

[2] The noncancer $TEQ_{DF,M}$ PRG is always lower than the PRG for the cancer endpoint for any given media and exposure scenario, and is therefore the more conservative PRG (see RI Report Tables 5-29 and 5-31).

For soil in the area south of I-10, a PRG was derived based on the reasonable maximum exposure scenario for a hypothetical future construction worker. For a noncancer hazard quotient equal to 1 the $TEQ_{DF,M}$ PRG for soil is 240 ng/kg (Anchor QEA 2015). The development of the PRG considers exposure to soil through the total depth interval (0- to 10-feet) to which a hypothetical future construction worker could be exposed. Figure 3-5 presents the depth-weighted average $TEQ_{DF,M}$ concentrations for the 0- to 10-foot depth interval for samples in the area south of I-10 relative to this PRG. At the request of USEPA, the $TEQ_{DF,M}$ soil exposure point concentration for a hypothetical future construction worker at those same locations was calculated in the 0- to 5-foot depth interval. The 0- to 5-foot depth-weighted average $TEQ_{DF,M}$ concentration in soil exceeds the PRG for the hypothetical future construction worker at four locations at stations, SJSB008, SJSB012, SJSB023, and SJSB025. These locations are co-located with the locations at which the 0- to 10-foot depth-weighted average $TEQ_{DF,M}$ exceeded the soil PRG for the hypothetical future construction worker (Figure 3-5).

3.2 Remedial Action Objectives

The RAOs discussed in this section were established to support the initial development and refinement of preliminary remediation goals (PRGs) during the RI/FS process and inform USEPA's selection of final remediation goals (or final clean-up levels) in the ROD.

The RAOs provided the first step in the process to define the chemicals and media to be addressed by the cleanup. The RAOs address specific exposure pathways and receptors, and provide the basis for defining PRGs. The RAOs for the areas within the USEPA's Preliminary Site Perimeter are provided below along with a brief summary of the extent to which RAOs have been addressed through implementation of the TCRA. The RI Report provides additional detail support for the development of the RAOs.

RAO 1: Eliminate loading of dioxins and furans from the former paper mill waste impoundments north and south of I-10, to sediments and surface waters of the San Jacinto River.

As outlined in the RI Report (Integral and Anchor QEA 2013), the RACR (USEPA 2012c), and subsequent ongoing TCRA monitoring, the Armored Cap has temporarily achieved RAO 1, with one exception, namely the exposed paper mill waste discovered in December 2015. Groundwater and porewater monitoring of the TCRA Site demonstrate that dissolved transport and loading of dioxins and furans through these pathways has been effectively addressed (Integral and Anchor QEA 2013).

The potential pathway for dioxin and furan loading to surface water and sediment from the possible impoundment south of I-10 described in the PSCR was surface runoff of soil particles. In comments on the Draft PSCR and on the Draft RI Report, USEPA raised concerns about migration of dissolved dioxins and furans with groundwater. The results of the RI Report indicate that $TEQ_{DF,M}$ concentrations in surface soils are below PRGs for the areas within Soil Investigation Area 4 south of I-10 and that pockets of dioxin-bearing waste are buried beneath several feet of soil; therefore, surface runoff of soil particles to surface water in this area is not an ongoing concern, and risk to hypothetical future commercial workers is also not a concern. Groundwater monitoring in the area south of I-10 also indicates that there is no potential for transport and loading of dioxins and furans to the aquatic environment through a groundwater pathway. Therefore, existing conditions in the area of investigation south of I-10 are consistent with RAO 1.

RAO 2: Reduce human exposures to paper mill waste-derived dioxins and furans from consumption of fish and shellfish by remediating sediments affected by paper mill wastes to appropriate cleanup levels.

Implementation of the TCRA has temporarily substantially reduced exposures of aquatic biota to wastes from within the Northern Impoundments, and therefore has reduced potential human exposures via fish and shellfish consumption. Implementation of the TCRA has temporarily achieved these objectives through elimination of direct contact exposure for fish and shellfish to wastes in the Northern Impoundments and impacted sediments. Implementation of ICs (fencing and warning signs) have also mitigated potential human exposures to fish and shellfish within USEPA's Preliminary Site Perimeter.

RAO 3: Reduce human exposures to paper mill waste-derived dioxins and furans from direct contact with intertidal sediment by remediating sediments affected by paper mill wastes to appropriate cleanup levels.

Estimated baseline risks under hypothetical exposure scenarios that involved direct contact with all areas within the USEPA's Preliminary Site Perimeter other than the Northern Impoundments, but did not involve ingestion of fish and shellfish, were below risk and hazard thresholds of concern. Implementation of the TCRA has temporarily substantially reduced potential cancer and noncancer dioxin hazards to people within USEPA's Preliminary Site Perimeter. An analysis of post-TCRA human health risk (Appendix F to the BHHRA Report) for the hypothetical recreational visitor and hypothetical recreational fisher found that both the noncancer and cancer hazard indices were reduced to below 1 for these receptors by implementation of the TCRA. Therefore, RAO 3 has been temporarily achieved through implementation of the TCRA. $TEQ_{DF,M}$ concentrations in surface sediment in all intertidal and subtidal areas outside of the TCRA Site are below applicable PRGs provided in Section 3.1.

RAO 4: Reduce human exposures to paper mill waste-derived dioxins and furans from direct contact with upland soils to appropriate cleanup levels.
The Armored Cap temporarily prevents exposure to soils containing paper mill waste within the TCRA Site unless the soil is exposed through excavation.

In the area of investigation south of I-10, the hypothetical future construction worker scenario indicated the potential for risk above thresholds considered acceptable by USEPA, due to exposure to dioxins and furans in the upper 10-feet of the soil column, in three specific locations. However, the dioxin and furan concentrations that cause the elevated exposures are in pockets of soil, each of which is at least 2-feet below the surface, and are therefore isolated from human contact as long as subsurface exposure during construction does not occur.

RAO 5: Reduce exposures of fish, shellfish, reptiles, birds, and mammals to paper mill waste-derived dioxins and furans by remediating sediment affected by paper mill wastes to appropriate cleanup levels.

Baseline risks associated with dioxins and furans to benthic macroinvertebrate communities and populations of fish, birds, mammals, and reptiles in the area north of I-10 and the aquatic environment were determined in the BERA to be negligible, except for risks to shorebirds (represented by the spotted sandpipers) and small mammals (represented by the marsh rice rat) that could live or forage in direct contact with the wastes or intertidal sediments in the impoundments north of I-10. Baseline ecological risks include reproductive risks to mollusks from exposure to 2,3,7,8-TCDD, primarily in the area of the Northern Impoundments. Baseline ecological risks elsewhere within the USEPA's Preliminary Site Perimeter were negligible, or were very low and the result of exposures to chemicals from sources other than paper mill wastes.

Analysis of post-TCRA risks to those ecological receptors that were potentially at risk under baseline conditions indicates that, because the TCRA temporarily eliminated exposures to dioxins and furans through direct ingestion of or direct contact with waste materials within the 1966 perimeter of the Northern Impoundments, the post-TCRA conditions do not pose a current risk for ecological receptors.

3.3 Applicable or Relevant and Appropriate Requirements

The development and evaluation of remedial alternatives, as presented in Section 5 of this document, includes an assessment of the ability of the remedial alternatives to address ARARs of environmental laws and other standards or guidance to-be-considered (TBC). Table 3-1 provides a summary of potential ARARs and TBCs that are considered in this FS Report. The list in Table 3-1 includes certain citations that are not applicable to the USEPA's Preliminary Site Perimeter to document the rationale for eliminating these regulations, standards, or guidelines from consideration. Many of the ARARs and TBCs in Table 3-1 are relevant to only some of the remedial alternatives, but all of the requirements that may be relevant to any of the remedial alternatives are identified in the list. Finally, USEPA may find during its review of remedial alternatives that the most suitable remedial alternative does not meet an ARAR. The NCP provides for waivers of ARARs under certain circumstances (see 40 Code of Federal Regulations [CFR] 300.430(f)(1)(ii)(C)).

After a remedy is selected, a detailed review of ARARs specific to the selected remedial action will be conducted and included in the Design Analysis Report for the selected action. The implementation of the remedy generally will not require Federal, State, or local permits because of the permit equivalency of the CERCLA remedy-selection process (40 CFR 300.400(e)(i)), but remedial actions will be completed in conformance with substantive technical requirements of applicable regulations.

The ARARs in Table 3-1 can be broken out into three different categories, although some ARARs may belong to more than one of these categories:

- Chemical-specific requirements
- Location-specific requirements
- Performance, design, or other action-specific requirements

Chemical-specific ARARs are typically the environmental laws or standards that result in establishment of health- or risk-based numerical values. When more than one of these chemical-specific ARARs are applicable to site-specific conditions, a remedial alternative should generally comply with the most stringent or conservative ARAR. Chemical specific ARARs presented in Table 3-1 include Clean Water Act (CWA) criteria and State water quality and waste standards. The development of PRGs within the USEPA's Preliminary Site Perimeter considered chemical-specific ARARs, as well as other generally accepted benchmarks for protection of human health and the environment.

Location-specific ARARs include restrictions placed on concentrations of hazardous substances or the implementation of certain types of activities based on the location of a site.

Some examples of specific locations include floodplains, wetlands, historic places, land use zones, and sensitive habitats. Location-specific ARARs presented in Table 3-1 include the Rivers and Harbors Act, Coastal Zone Management Act, and Federal Emergency Management Agency/National Flood Insurance Program regulations.

The action-specific ARARs are generally technology or activity-based limitations or guidelines for management of pollutants, contaminants, or hazardous wastes. These ARARs are triggered by the type of remedial activity selected to achieve the RAO and these requirements may indicate how the potential alternative must be achieved. Action-specific ARARs presented in Table 3-1 include CWA water quality certifications (Section 401) and discharges of dredged and fill material (Section 404), Clean Air Act, Endangered Species Act (ESA), and other wildlife protection acts.

The following sections discuss ARARs that have the most significance to the evaluation of remedial alternatives for the USEPA's Preliminary Site Perimeter. Action-specific ARARs do not apply to all of the remedial alternatives. For example, requirements for waste management and hazardous materials transportation are most significant for remedial alternatives that involve removal of sediment, and would not apply at all to remedial alternatives that do not include removal of material from within the USEPA's Preliminary Site Perimeter. The types of actions that would trigger compliance with these requirements are also discussed.

3.3.1 Water Quality and Water Resources

3.3.1.1 Section 303 and 304 of the Clean Water Act and Texas Surface Water Quality Standards

Section 303 of the CWA requires states to promulgate standards for the protection of water quality based on Federal water quality criteria. Federal water quality criteria are established pursuant to Section 304. Texas Surface Water Quality Standards are relevant to the evaluation of short-term and long-term effectiveness of the remedial alternatives.

Demonstration of substantive compliance with these ARARs will be achieved using:

- Best Management Practices (BMPs) incorporated into the design to support water quality and attainable use standards for this section of the San Jacinto River. These BMPs include the use of protective berms (either raised or constructed), sheet pile walls within the berms to strengthen and seal the berms and to aid dewatering, establish the top elevation of walls to provide protection from larger floods (i.e., 50-

year return period floods), armor external side of the berms with removed armor cap material to control erosion, remove armored cap and geotextile/geomembrane and sediment in the dry to the extent practicable, and silt fences to manage re-suspension.

- Installing the sheet pile walls at the top of the berms would provide more support for the wall, facilitate sealing joints between the sheet piles above the berm, and reduce the potential leakage through the wall and berms since the wall would not be exposed to the water column except during very high flow conditions. Excavation and backfilling in the dry will eliminate potential resuspension and residuals losses.

- Although driving sheet piles through the existing TCRA Cap allows coverage of the contaminated sediments during construction, it is not recommended because of the difficulties associated with driving sheet pile through the large armor rock, and achieving a tight seal between joints. Instead, a portion of the rock armor should be removed from the sheet pile footprint, and the geotextile or geomembrane cut and peeled back to avoid damage or shifting during sheet pile installation. Activities associated with driving the sheet pile will disturb the exposed sediment causing some limited resuspension, considering that the sediment has been consolidated under the armor cap and geotextile. Additionally, the impact should be relatively small due to the small footprint required for the sheet pile.

- To manage potential upland runoff, plastic sheeting would be used to cover any required upland stockpiles, and other erosion control measures to be described in the plans and specifications of the final remedy.

- To reduce the dredge residuals having a high concentration of contaminants, a clean-up pass would be included in the dredge plan to reduce the future exposure. Additionally, a 12-inch residuals cover would be placed in two 6-inch lifts to limit intermixing of residuals with the fill so that the bioactive zone would be clean following remediation and would yield less diffusive flux than the existing TCRA cap without a geomembrane.

- During the course of construction activities suspended sediments will accumulate within the enclosed area; however, considering the brackish nature of the site water flocculation and settling will maintain relatively low concentrations of total suspended solids, probably a concentration of less than 250 mg/L, within the enclosure. Upon removal of the sheet pile, this sediment laden water may be released allowing transport of contaminants offsite. At a minimum, it is suggested to allow time for particulates to settle after construction activities cease prior to sheet pile removal, the vast majority of the suspended solids should settle within a day. Flocculants may also be used to promote settling and create dense, strong flocs that would settle in minutes. Furthermore, dispersal of activated carbon may be used to adsorb dissolved contaminants. Once deposited on the bottom, the carbon would continue to treat contaminants on the surface.

- Water quality monitoring, performed as described in the Water Quality Monitoring Plan that will be developed to detect potential impacts on water quality and trigger the implementation of additional BMPs or an interruption of construction if necessary.

3.3.1.2 Section 401 Water Quality Certification of the Clean Water Act as Administered by Texas

Section 401 requires that the applicant for Federal permits obtain certification from the appropriate State agency that the action to be permitted will comply with State water quality standards. Although environmental permits are not required for on-site CERCLA response actions, the selected remedy will incorporate elements to comply with State water quality standards. Consultation with the TCEQ may be necessary to confirm that the final design of the selected alternative meets the substantive requirements of Section 401 of the CWA.

Documentation of substantive compliance with this ARAR would include:

- Coordinating with TCEQ regarding the information required in the Section 401 "Tier 2" Water Quality Certification questionnaire and incorporating agency feedback in the design, if needed.

- Providing documentation of the consultation to USEPA.

3.3.1.3 Section 404 and 404 (b)(1) of the Clean Water Act

Section 404 requires that discharges of fill to waters of the United States serve the public interest. In selecting a remedial alternative including discharge of fill, USEPA would be required to make the determination that the placement of materials into the San Jacinto River serves the public interest as necessary to remediate source material from within the USEPA's Preliminary Site Perimeter.

The area within the USEPA's Preliminary Site Perimeter includes wetlands in the area north of I-10, and a plan will need to be established that addresses the requirements (to the extent practicable) of Section 404 and 404(b)(1). The Respondents previously prepared a report on potentially jurisdictional waters of the U.S. (including wetlands) (Anchor QEA 2010; Anchor QEA 2011) as part of the TCRA implementation in compliance with the 1987 USACE Wetlands Delineation Manual and Interim Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Atlantic and Gulf Coastal Plan Region. A supplemental draft 404(b)(1) report may need to be prepared for consideration by USEPA depending on the nature of the selected remedy.

Specific BMPs anticipated to be included in construction actions, to minimize the impacts of discharges of fill into the water, include:

- The use of armored berms, sheet piles, and silt curtains and debris booms around in-water work areas
- The use of upland erosion controls such as plastic covering of stockpiles
- The use of silt fencing around upland areas
- Construction of a stable upland haul route capable of handling construction traffic without creating ruts that would develop into a source of turbid water
- Monitoring and maintenance during construction to ensure these BMPs are functioning as designed

3.3.1.4 Texas Pollutant Discharge Elimination System

Within the State of Texas, the National Pollutant Discharge Elimination System (NPDES), which demonstrates compliance with Section 402 of the CWA, is administered by TCEQ and referred to as Texas Pollutant Discharge Elimination System (TPDES). To demonstrate substantive compliance with TPDES, the following measures will be taken:

- The contractor will be required to prepare a Storm Water Pollution Prevention Plan (SWPPP) in accordance with the general permit requirements of TXR150000 (the TPDES permit for construction activities).
- The contractor will be required to implement appropriate monitoring during construction.

3.3.1.5 Rivers and Harbor Act and Texas State Code Obstructions to Navigation

The USEPA's Preliminary Site Perimeter is within a navigable waterway, and the State of Texas regulates the obstruction of navigable waters within the State involving the construction of structures, facilities, and bridges or removal and placement of trees that would obstruct navigation (Riddell 2004). The State of Texas considers land within the bed and banks of rivers to be public and requires access for the public to such areas. With the exception of the TCRA Site, which is required to be restricted to minimize the potential for disturbance of the Armored Cap by vehicular traffic or vandalism, the remedial alternatives will not limit public access.

Documentation of compliance with this ARAR would entail documenting, with State concurrence, the extent to which a remedial alternative would affect navigability of the San Jacinto River in the vicinity of the USEPA's Preliminary Site Perimeter.

3.3.2 Protected Species Requirements

This section addresses requirements of the ESA, the Fish and Wildlife Coordination Act, the Bald and Golden Eagle Protection Act, and the Migratory Bird Treaty Act. The area within the USEPA's Preliminary Site Perimeter surrounds a section of a major highway including an overpass; however, the USEPA's Preliminary Site Perimeter is upstream of Galveston Bay, which provides rearing, spawning, and adult habitat for numerous marine and estuarine fish and invertebrate species including blue crab, drum, flounder, oysters, spotted sea trout, and shrimp. Sea turtles, including the Federally listed green, hawksbill, Kemp's Ridley, leatherback, and loggerhead turtles occasionally enter Galveston Bay to nest and feed National Oceanic and Atmospheric Administration (NOAA 2010a). The National Marine Fisheries Service (NMFS) includes the ESA-listed sea turtles in Trust resources, but these turtles are not likely to be present within the USEPA's Preliminary Site Perimeter. The design and overall goal of the remedial action is to improve habitat conditions through the anticipated reduction of potential exposure to COCs.

To address concerns regarding presence of protected species, the Respondents retained a qualified biologist to conduct a threatened and endangered species (TES) survey. The TES survey led to a determination that there is no likely presence of protected species and their habitat within the USEPA's Preliminary Site Perimeter (Anchor QEA 2010a). Moreover, the BERA concluded that under baseline and post-TCRA conditions, there is no risk to the protected species that were evaluated.

Further documentation of compliance with the protected species requirements would include:

- Incorporation of BMPs into the design to prevent or minimize incidental construction-related releases that could potentially impact protected species off-site.

- Pursuant to CERCLA Section 121(e) and USEPA policy, consultation with the U.S. Fish and Wildlife Services (USFWS) and NMFS is needed to confirm that the implementation of the proposed remedy will have no effect on listed species or habitat.

3.3.3 Coastal Zone Management Act and Texas Coastal Management Plan

Federal agency activities that have reasonably foreseeable effects on any land or water use or natural resource of the coastal zone (also referred to as coastal uses or resources and coastal effects) must be consistent to the maximum extent practicable with the enforceable policies of a coastal State's Federally approved coastal management program (NOAA 2010b). The Texas General Land Office (GLO) administers the Texas Coastal Management Consistency certification process.

Substantive compliance with the certification would be demonstrated by:

- Evaluating the effects of the proposed remedy on critical areas (if any) and associated criteria including no net loss of critical area functions and values.

- Evaluating the remedy for compliance with the Texas Coastal Zone Management Consistency Determination and policies identified in the application for Consistency with the Texas Coast Management Program.

- Supporting the USEPA's consultation with the Galveston District USACE and Texas GLO.

3.3.4 Floodplain

A hydrologic evaluation (Appendix B) was performed to evaluate the impacts of the remedial alternatives on the water levels in the San Jacinto River. The evaluation of potential effects of the remedial alternatives on flooding is discussed in the detailed evaluation of the remedial alternatives in Section 5.

3.3.5 Cultural Resources Management

No historic properties eligible for listing in the National Register of Historic Places (NRHP) are recorded within the USEPA's Preliminary Site Perimeter (Anchor QEA and Integral 2010a).

3.3.6 Noise Control Act

Noise abatement may be required if actions are identified as a public nuisance. Due to the TCRA Site being bounded by water on three sides and adjacent to a highway overpass on the fourth side and the industrial activities in the area south of the I-10, noise from the construction activity is unlikely to constitute a public nuisance. If necessary, BMPs would be implemented to reduce the noise levels. If materials are delivered to or removed from the project area by truck, noise greater than 60 decibels in close proximity to sensitive receptors (schools, residential areas, hospitals, and nursing homes) will be avoided. Truck routes will be selected to avoid sensitive receptors to the extent possible.

3.3.7 Hazardous Materials Transportation and Waste Management

Remedial alternatives 5N, 5aN, 6N, and 4S (presented in Section 4) include removal and transportation of sediments to an off-site disposal facility. Off-site disposal would also be required for limited quantities of waste, such as used personal protective equipment (PPE) and any debris or vegetated materials required to be removed during clearing and grading activities, associated with all of the remedial alternatives except for no further action. The contractor will be required to package any hazardous materials in appropriate containers and label containers in accordance with Texas Department of Transportation (TxDOT) requirements. The development of remedial alternatives anticipates that all disposal will be at a permitted landfill facility. If an off-site facility needs to be established for dewatering sediment or transloading waste from barges to trucks or rail cars, it may require a solid waste permit.

4 DEVELOPMENT OF REMEDIAL ALTERNATIVES

4.1 Remedial Technologies Screening

The RAM (Anchor QEA 2012b) identifies General Response Actions (GRAs) and provides initial screening of remedial technologies. In addition, the RAM describes the development of a set of preliminary remedial alternatives for the area north of I-10 to achieve a range of post-remedy SWACs. Subsequent to development of the RAM, the range of remedial alternatives was modified to include those that are described in this FS Report. The following supplemental information regarding GRAs is provided in the specific context of the final set of remedial alternatives considered in this FS Report.

4.1.1 Institutional Controls

ICs are administrative measures that are implemented to mitigate risks or to protect the integrity of engineered controls. ICs include "Proprietary Controls," which are restrictions placed on the use of private property, "Governmental Controls," which include restrictions on the use of public resources, "Enforcement Tools" that may be imposed by an agency to compel certain actions, and "Informational Devices," which include notices about the presence of contamination or fishing advisories.

Governmental controls, enforced by state or local government, may include bans on harvesting fish or shellfish, zoning restrictions, ordinances, statutes, building permits, or other restrictions. Zoning may be used by local governments to designate land use for specific purposes. Government ordinances or permits may also restrict or control land uses, and outline specific requirements before authorizing certain activities (e.g., building codes, drilling permit requirements). Some local ordinances place controls on access to or use of certain areas within a property.

Proprietary controls are based on real property law (EPA 2000). Enforceability of proprietary controls should be evaluated under applicable (state) law. Some proprietary controls are enforceable upon execution, others upon the sale or transfer of property. Examples include easements, covenants, and conservation easements. Easements are rights over the use of another's property, and include negative easements which limit uses that would otherwise be lawful. Access easements are sometimes used to ensure current and future property owners allow property access to operate, monitor, or maintain ECs or ICs. Covenants are agreements between the landowner and others connected to the land. They are typically used to establish an IC when property is transferred to another party. Use restrictions/ statutes/ environmental covenants are state statutes that provide owners of a contaminated property with authority to establish use restrictions. Conservations easements are state statutes that establish easements to conserve property or natural resources. Enforcement and permit tools include permits, administrative orders, and consent decrees which are enforceable by state or federal agencies. Most enforcement agreements are binding on only the signatories and do not bind subsequent owners. Examples include administrative orders which are issued by an environmental regulatory agency directing property owners to perform (or not perform) certain actions. Consent decrees document an administrative or judicial court's approval of the settlement of an enforcement case filed in court. These typically specify actions to be taken (or not to be taken) by the settling parties. Permits are implemented by an environmental regulatory agency and may require compliance with a statutory or regulatory provision that may impact the reuse of the property.

Informational devices provide information to the public about risks from contamination and generally are not legally enforceable. Informational devices include deed notices, state registries of hazardous waste sites, and advisories. Deed notices are filed in public land records with the property deed that provide information about potential health risks from contamination left on the property. Advisories warn the public of potential risks associated with using contaminated land surface water or groundwater, generally issued by public health agencies.

In addition to the legal mechanisms mentioned above, the Uniform Environmental Covenants Act (UECA) is a model statute that can be adopted into law by each individual state or territory. The UECA provides legal framework to create, modify, enforce and terminate a valid real estate instrument (environmental covenant or IC) to restrict use of contaminated real estate or impose obligations under state law and precluded the application of traditional common law doctrines that might otherwise hinder the validity or enforcement of ICs adopted under state property law or other mechanisms. The UECA provides a legal mechanism to ensure LUCs can be readily found, maintained, and enforced over time.

Layering of ICs, using different types of ICs at the same time may enhance protectiveness. Applying ICs in series may help ensure both short- and long-term effectiveness. Using ICs in conjunction with physical barriers to limit access is also recommended.

The three most common types of ICs at sediment sites include fish consumption advisories and commercial fishing bans, waterway use restrictions, and land use restriction/structure maintenance agreements. Fishing advisories, restrictions or bans on fishing (including shell fishing) are typical ICs. Commercial fishing bans are government controls that ban commercial fishing for specific species or sizes of fish or shellfish (EPA 2005). Rather than a complete ban, advisories may be placed on certain locations and types of fishing. Advisories inform the public that they should not consume fish from an area or should limit the number of fish meals consumed over a specific time period. Advisories and bans are usually established by state departments of health and can be administered through signs, pamphlets or other outreach materials. Warning signs should be in the language of the local community including new immigrants, and require periodic inspection and maintenance. Monitoring, enforcement and communication with local or state authorities are required. Consumption advisories are not enforceable controls and may have variable effectiveness. Surveys of anglers are often helpful to evaluate whether they consume the fish they catch and whether restrictions are effective. EPA's Fish Advisory Program compiles a national listing of fish advisories through its Office of Science and Technology.

Institutional controls may also be needed to protect the integrity of the remedy. Land use restrictions may be needed at near-shore or upland sites to limit or eliminate construction activities, digging or other activities that may disturb the contaminated materials. A deed restriction or notice may be adequate for an upland property, but for in-water remedies, restrictions may be more difficult due to ownership issues. Nearshore areas can, in some cases, be privately owned out to the end of piers. If privately owned, traditional ICs such as proprietary controls or enforcement tools can be considered. Federal, state and local laws place restrictions on and require permits for dredging, filling, or other construction activities in the aquatic environment. ICs may also be implemented through coordination through existing permitting processes.

Restrictions on vessel traffic to establish no-wake zones or restrictions against anchoring may be necessary to protect a cap. Restrictions on easements for installation of utilities and other in-water construction may also be needed, and should be placed on navigational charts. Navigational buoys or warning flags can be used to help warn boaters (ASTSWMO 2009). Changing the navigation status of a waterway may also be necessary. De-authorization or re-authorization of federally authorized navigation channels to a different width or depth would be required. The state may have authority to change harbor lines or the navigation status.

The ICs for all northern area alternatives except Alternative 1N include establishing limitations on dredging and anchoring within the footprint of the Armored Cap. Limitations on dredging and anchoring would be established by requesting that the U.S. Coast Guard District Commander establish a regulated navigation area. The intent of Alternative 6N is full removal of all materials exceeding the PRGs potentially allowing for less restricted future use of the property. If successful, future controls may for Alternative 6N not be necessary. However, if dredging residuals leave a layer of material exceeding PRGs, ICs will be needed for Alternative 6N, including a no-wake zone to protect the residuals cover. Additional measures are required to alert future property owners of the presence of subsurface materials exceeding PRGs and management requirements for any excavated soils or sediment exceeding the PRGs. For the northern nearshore areas and the upland area of the southern impoundment, the ICs would include land use restrictions against construction, excavation, or other disturbances that may expose contamination. The ICs would be established using proprietary controls such as covenants to alert future landowners of the potential risks and restrictions. The ICs would be needed until such time as resulting concentrations are shown to be acceptable.

4.1.2 Monitored Natural Recovery

MNR would entail periodic sampling and an analytical program that would be implemented to monitor the progress of natural recovery. Sampling would be conducted at a representative range of locations and at appropriate time intervals to allow trends in concentrations to be assessed. The scope of the MNR sampling and analysis, and any adaptive management actions that could be taken as a result of the MNR assessment, would be determined during remedial design and based on discussions with USEPA.

4.1.3 Treatment

Treatment processes are screened and discussed in the RAM (Anchor QEA 2012b). Treatment alternatives considered in this FS include S/S of soils and sediments with a reagent such as Portland Cement. S/S was successfully performed during the TCRA on a portion of the Western Cell materials. For costing purposes, the FS assumes a treatment reagent and dosage concentration similar to that which was used during the TCRA, or 7 to 8 percent by weight Portland cement (USEPA 2012c).

To accomplish S/S, physical removal of the existing Armored Cap materials, as well as the overlying surface waters will be required prior to mixing the reagent. This FS Report assumes that treatment areas in the Eastern Cell that are normally inundated would need to be surrounded by a sheetpile wall, and the water drawn down prior to initiating S/S. The sheetpile system used would need to be robust to withstand differential water levels inside and outside the treatment cell. Sheetpile walls can be overwhelmed during major storm and flood events in the river. In these circumstances, it is likely that releases of wastes that are exposed as a result of construction activities would occur. Finally, given the physical constraints of the TCRA Site, an off-site materials management facility is anticipated to be necessary for temporary stockpiling of cap materials, treatment reagents, and associated machinery to implement the S/S.

4.1.4 Containment

As described in the RAM, to the extent that containment is a component of the remedy, the containment would be designed, monitored, and maintained in accordance with USACE and USEPA capping guidance (USACE 1998). In addition, the specific recommendations by USACE to enhance the Armored Cap (see Section 2) are incorporated into any alternative that includes capping as an element.

In situ capping, as discussed in USEPA guidance (USEPA 2005) is a demonstrated technology that has been selected by USEPA for sediment remediation sites across the United States (USACE 1998). Compared to removal-focused approaches, in situ capping has a disadvantage, in that caps require monitoring and maintenance to ensure their protectiveness. Table 4-1a presents a summary of projects similar to the SJRWP Site where capping was a component of the remedy. Caps constructed for these projects isolate dioxin-contaminated soils and sediments or related constituents, and are located in river or marine environments where a portion of the cap is above the typical water surface, and/or a portion of the cap is submerged. These caps have been monitored, and in some cases maintained, in accordance with approved OMM plans. Monitoring has demonstrated that these caps are protective.

The existing Armored Cap was designed in accordance with USEPA and USACE capping guidance (USACE 1998). As described in the TCRA Removal Action Work Plan (Anchor QEA 2011) and required by the TCRA AOC, the armor rock was designed to withstand a 100-year storm event with an additional factor of safety to ensure its long-term protectiveness. The storm event defines the depth of water and the currents that the cap armor layer must resist. In addition to the 100-year event, storms with 5- and 10-year return intervals were also considered during the TCRA design because it was recognized that more frequent storms could present more critical design conditions; for these more frequent storms, the water depth at the Site would be lower, which could result in higher shear stresses on the cap compared to a less frequent storm like the 100-year design event.

Although a 100-year event was specified for the TCRA design, to assess the potential risk of an even larger storm, events up to the 500-year storm were evaluated for the FS, and intermediate storms with 25- and 50-year return intervals were also modeled (Appendix B). As is shown in Appendix B, the critical design storms for the TCRA Site occur between the 10- and 100-year return intervals. For less frequent, larger storms, the greater depth of water at the TCRA Site due to flooding results in lower velocities, and thus lower shear stresses acting on the cap.

Surface flow and wave break modeling was performed to evaluate potential erosive forces to support the selection of cap materials to resist those forces (Appendix B). The modeling considers wind and vessel generated waves breaking in the surf zone, as well as river currents under a variety of design storm and flood scenarios. This modeling is described in more detail in Appendix B.

Cap design occurs with requirements for OMM in mind. Since being completed in July 2011, the Armored Cap and associated fencing, access controls and signs have been routinely inspected and maintained by Respondents pursuant to a USEPA-approved OMM Plan. The OMM Plan was developed to address conditions that USACE and USEPA cap design guidance expressly presumes could occur post-construction (such as movement of rock cover in localized areas of the cap). The OMM Plan requires periodic monitoring and monitoring following key storm events to identify the need for possible cap maintenance, followed by appropriate repair activities (USEPA 2005; USACE 1998). The first few years following cap construction is a period where monitoring and maintenance is more frequent. At least two other sediment caps with demonstrated performance over the last 20+ years have followed this progression. The St. Paul Waterway cap (USEPA 2004b) and the Eagle Harbor cap (USEPA 2012d), constructed in the late 1980s and early 1990s respectively, required some early maintenance in their first few years. Subsequent monitoring has demonstrated the continued protectiveness of these sediment caps.

Cap protection from future barge or other vessel operations in the Armored Cap area would be assessed and detailed during the remedial design phase. For purposes of FS cost development, a conceptual submerged perimeter rock berm has been included as a protective perimeter barrier for the alternatives that include the Permanent Cap to further ensure the long-term protectiveness of the cap by reducing potential for vessel impacts. Finally, given the physical constraints of the TCRA Site, an off-site staging area is anticipated to be necessary for temporary stockpiling of cap materials, similar to that which was utilized during construction of the TCRA.

Capping is considered to be highly compatible with the Armored Cap in accordance with the TCRA Removal Action Objectives (USEPA 2010a, Appendix A, V.A.2), because the existing Armored Cap would not need to be disturbed to implement this remedial action.

4.1.5 Removal

Sediment removal has been the most frequent cleanup method used by the Superfund program at sediment sites. Dredging or excavation has been selected as a cleanup method for contaminated sediment at more than 100 Superfund sites (USEPA 2005). One of the advantages of removing contaminated sediment from the aquatic environment often is that, if it achieves cleanup levels for the site, it may result in the least uncertainty about long-term effectiveness of the cleanup, particularly regarding future environmental exposure to contaminated sediment. Removal of contaminated sediment can minimize the uncertainty associated with predictions of sediment bed or cap stability and the potential for future exposure and transport of contaminants. Another potential advantage of removing contaminated sediment is the flexibility it may leave regarding future use of the water body. Methods such as MNR and capping frequently include institutional controls (ICs) that limit water body uses (USEPA 2005). Table 4-1b includes a list of representative projects with conditions similar to this Site where dredging has been chosen as the remedy.

Alternatives that involve full or partial removal of the Armored Cap and excavation of impacted material from beneath the cap and in other locations all involve excavation and dredging to some extent. As discussed in the RAM (Anchor QEA 2012b), virtually all dredging projects result in some degree of resuspension, release, and residuals, despite use of BMPs (USEPA 2005, Sections 6.5.5 (resuspension and releases) and 6.5.7 (residuals); NRC 2007; USACE 2008; Bridges et al. 2010). Empirical data from numerous sediment remediation projects indicate that residual contamination is a common occurrence that frequently limits the overall protectiveness of removal (Patmont and Palermo 2007; NRC 2007). USEPA guidance on sediment remediation states that “there should not be necessarily a presumption that removal of contaminated sediments from a water body will be necessarily more effective or permanent than capping or MNR.” (USEPA 2005).

Operational and engineering controls (rigid and flexible barriers) would be used to the extent practicable to mitigate these potential releases; however, case studies have shown that engineering controls used to control impacts from dredging such as sheetpiles may have limited effectiveness, are subject to leakage, accumulate resuspended sediments at the base of the walls which is impossible to completely capture, and have other technical limitations (USACE 2008b; Anchor Environmental 2005; Anchor QEA and Arcadis 2010). Further, use of rigid barriers can result in unintended consequences, such as localized scour adjacent to the barrier, and/or the spread of contaminants during structure removal (Ecology 1995; Konechne et al. 2010; Anchor QEA and Arcadis 2010). Flexible barriers such as turbidity curtains will suffer from suspended sediment losses because these types of barriers are not truly water-tight (USACE 2008a; USACE 2008b; Francingues and Palermo 2006; Anchor

Environmental 2005; Anchor QEA and Arcadis 2010). Proper design and installation of engineered barriers would be critical for minimizing the issues described above.

Dredging residuals would be managed by backfilling the dredge footprint, or by placement of a clean sediment cover or engineered cap over the dredge footprint. For purposes of this FS Report, it has been assumed that backfill and capping would be used to manage residuals for removal-based alternatives that do not achieve the PRG, and a nominal 6-inch-thick cover of clean sediment would be used to manage dredging residuals for removal-based alternatives that achieve the PRG.

Construction-related releases associated with removal-based alternatives reduce the long-term effectiveness of these approaches. Table 4-2 presents a summary of dredging release case studies. Post-construction monitoring data have shown that dredging-based cleanup remedies can increase fish tissue concentration of contaminants, even several years following completion of dredging (e.g., at the Commencement Bay and Duwamish Waterway Superfund Sites; Patmont et al. 2013). To the extent that dredging-related releases occur, they reduce the overall effectiveness of a dredging remedy and under USEPA sediment remediation guidance (USEPA 2005, Sections 6.5.5 and 7.4), this should be considered during the comparative net risk analysis of the remedial alternatives under consideration.

Dredging-based alternatives would require the removal of all or portions of the existing Armored Cap to access the target material. Based on the history of resuspension, releases and residuals that occur despite use of BMPs (as identified by USEPA, the National Academy of Sciences, the USACE, and others), it is likely that some of these risks would occur at this Site in connection with the removal alternatives being considered. Under the USEPA sediment remediation guidance (USEPA 2005), these factors should be taken into consideration when comparing the dredging remedies to the overall effectiveness of those alternatives that do not involve additional soil and sediment dredging/excavation.

The estimated construction durations for the removal-based alternatives range from 13 months to 19 months. If a major storm or flood were to occur during construction of a dredging-based remedy, any BMPs that may be instituted to control dredging residual releases under normal flow conditions may be overwhelmed. In these circumstances, releases of disturbed wastes to the river that are exposed as a result of construction activities may be exacerbated. The risk of this type of occurrence is discussed for each dredging-based alternative under the short-term effectiveness evaluations in Section 5. Finally, given the physical constraints of the TCRA Site, an off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill.

Upland excavations for the area of investigation south of I-10 would be accomplished with conventional earthwork equipment (excavators, dozers, loaders, etc.). Considerations related to upland excavations include maintaining stable sidewalls, and managing water for those excavations that must be performed below the groundwater table.

To maintain stable sidewalls, the excavation may be sloped to a stable angle of repose if space permits, or shoring could be used. Earthwork safety guidelines generally require any excavation deeper than 5-feet to have sloped or shored sidewalls, as provided for in 29 CFR 1926.651 and 1926.652 (Occupational Safety and Health Administration [OSHA] 2014).

Excavation water controls could include ditches and sumps, well point systems, or deep wells. The dewatering effluent may need to be treated prior to disposal or shipped to licensed facility depending on the quality of the water. The selection of appropriate dewatering technology and decisions about dewatering effluent treatment are remedial design elements.

4.1.6 Disposal

The RAM included consideration of incineration as a component of disposal. At the time the RAM was developed, it was unclear whether there were landfill facilities that would accept dredged or excavated material from the Site. Subsequent to submittal of the RAM and the Draft FS Report, two landfill facilities were tentatively identified that indicated materials from the SJRWP Site could potentially be disposed of at these locations without incineration. Thus, further consideration of incineration as a component of disposal has been screened out in this FS Report.

Given the limited upland space available adjacent to the TCRA Site, an off-site facility with water access would be necessary unload barges and process dredged sediment prior to shipment to the landfill. The off-site facility would need to accommodate stockpiles for armor rock and dredged material, and would need space to accommodate a sediment drying process (conceptually envisioned to be mixing in a drying reagent for this FS Report). The off-site facility would also need to accommodate any water treatment and disposal determined necessary during remedial design. Some operations, such as water treatment, could also be barge mounted. Finally, the off-site facility would need access to regional transportation infrastructure such as heavy-duty roads or rail.

Even with ready access to the regional transportation infrastructure, off-site disposal has posed a bottleneck for some sediment remediation projects (Anchor Environmental and Windward Environmental 2005; Anchor QEA 2009). The daily capacity of the landfill facility to receive material, and/or the daily capacity of the transportation infrastructure to accommodate a new waste stream can be limited. The durations presented in this FS Report have assumed there are no transportation or landfill bottlenecks, and that these facilities can receive material at the same rate as it is excavated or dredged. To the extent that any disposal bottlenecks occur, this would increase the overall duration of removal-based alternatives, exacerbating community, traffic, and safety impacts.

4.2 Assembly of Remedial Alternatives

The preliminary remedial alternatives were modified subsequent to submittal of the RAM. The most significant reason for the modifications was that PRGs for sediment and soil (as described in Section 3.1) had not been developed when the RAM was prepared. Based on a comparison of $TEQ_{DF,M}$ concentrations in sediment and soil to the PRGs, areas of affected sediment and soil potentially subject to remedial action have been identified and are discussed in the descriptions of the remedial alternatives in the following subsections. Remedial alternatives were developed for the FS at the direction of and in coordination with USEPA Region 6 for the areas north and south of I-10. The remedial alternatives for the area north of I-10 are:

- **Alternative 1N – Armored Cap and Ongoing OMM (No Further Action)**, which assumes the Armored Cap would remain in place, together with fencing, warning signs and access restrictions established as part of the TCRA, and would be subject to the ongoing OMM program. The estimated cost of this alternative is $9.5 million. This estimate includes the cost of Armored Cap design and construction and USEPA 5-year reviews; these same costs are included in the estimate for each of the other alternatives for the area north of I-10.

- **Alternative 2N – Armored Cap, ICs and Monitored Natural Recovery (MNR),** which includes the actions described under Alternative 1N, ICs in the form of deed restrictions and notices, and periodic monitoring to assess the effectiveness of sediment natural recovery processes. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. This alternative is estimated to cost $10.3 million.

- **Alternative 3N – Permanent Cap, ICs and MNR,** which includes the actions described under Alternative 2N plus additional enhancements to the Armored Cap, many of which have already been implemented during the work performed in January 2014, consistent with the USACE recommendations. This alternative will increase the long-term stability of the Armored Cap consistent with permanent isolation of impacted materials (Permanent Cap) and meet or exceed USACE design standards. This alternative also includes additional measures to protect the Permanent Cap from potential vessel traffic (i.e. a protective perimeter barrier). This alternative would require an estimated 2 months of construction at an estimated cost of $12.5 million. An off-site staging area would likely be required for management of rock armor, similar to that which was utilized during the TCRA construction. However, the exact location and configuration of the off-staging area are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 4N – Partial Solidification/Stabilization, Permanent Cap, ICs and MNR,** provides for solidification and stabilization (S/S) of the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. This alternative includes the actions described under Alternative 3N; however about 23 percent of the Armored Cap (2.6 acres above the water surface and 1.0 acre in submerged areas) would be removed and about 52,000 cubic yards (cy) of materials beneath the cap with $TEQ_{DF,M}$ that exceeds a concentration of 13,000 ng/kg, would undergo S/S. After the S/S is completed, the Permanent Cap would be constructed. This alternative would require an estimated 17 months of construction to complete and is estimated to cost $23.2 million. An off-site staging area may be required for management of rock armor, stabilization reagents and associated treatment equipment. However, the exact location and configuration of the off-staging area are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 5N – Partial Removal, Permanent Cap, ICs and MNR,** provides for removal of the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. Under this alternative the Armored Cap would be partially removed and the same 52,000 cy of material that would undergo S/S under Alternative 4N would instead be excavated for off-site disposal. After the removal was completed, the Permanent Cap would be constructed and the same ICs and MNR that are part of Alternatives 2N to 4N would be implemented. This alternative would require an estimated 13 months of construction at an estimated cost of $38.1 million. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. The exact location, configuration, siting and operational impacts, as well as potential delivery restrictions by the receiving facility (e.g., tons per day) are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 5aN - Partial Removal of Materials Exceeding the PRG, Permanent Cap, ICs and MNR,** in which all material beneath the Armored Cap in any location where the water depth is 10-feet or less and which has a of $TEQ_{DF,M}$ 220 nanograms per kilogram (ng/kg) or greater[6] – about 137,600 cy – would be excavated for off-site disposal. To implement this alternative, about 11.3 acres (72 percent) of the Armored Cap would be removed to allow for this material to be dredged. After excavation of the material, the remaining areas of the Armored Cap would be enhanced to create a Permanent Cap, and the same ICs and MNR that are part of the preceding alternatives would be implemented. This alternative would require an estimated 19 months for construction and has an estimated cost of $77.9 million. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. The exact location, configuration, siting and operational impacts, as well as potential delivery restrictions by the receiving facility (e.g., tons per day) are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

- **Alternative 6N – Full Removal of Materials Exceeding the PRG, ICs and MNR,** in which all material above the PRG of 200 ng/kg beneath the Armored Cap and at depth in an area to the west would be removed. This would involve removal of the existing Armored Cap in its entirety and the removal of 200,100 cy of material. The dredged area would then be covered with two layers of clean fill. This alternative would require an estimated 16 months of construction at an estimated cost of $99.2 million. An off-site materials management facility will be required for material staging, stabilization and processing for bulk transportation to an off-site landfill. The exact location, configuration, siting and operational impacts, as well as potential delivery restrictions by the receiving facility (e.g., tons per day) are beyond the scope of this FS and may not be fully reflected in the FS estimated durations or costs.

The remedial alternatives for selected locations within Soil Investigation Area 4 south of I-10 are:

- Alternative 1S – No Further Action

- Alternative 2S – ICs

[6] In defining this alternative, USEPA included an additional requirement that all material exceeding 13,000 ng/kg $TEQ_{DF,M}$, regardless of water depth, would be removed. However, all locations that exceed 13,000 ng/kg $TEQ_{DF,M}$ are in areas with 10-feet of water or less. Thus, the horizontal boundary defining this alternative (the 10-foot water depth) includes all locations exceeding 13,000 ng/kg $TEQ_{DF,M}$.

- Alternative 3S – Enhanced ICs
- Alternative 4S – Removal and Off-site Disposal

A brief description of the primary elements for each alternative is provided in the remainder of this section, and Tables 4-3 and 4-6 provide a summary of material quantities and durations associated with each of the alternatives. Note that the footprint and assumptions for each alternative are based on the available RI data. Data gaps potentially exist that would need to be addressed during remedial design depending on the selected remedial alternative. For example, to the extent that the selected alternative includes solidification, laboratory bench scale testing would be performed during remedial design to select reagent types and dosages for solidification. Alternatively, if the selected alternative includes removal, additional data would be collected during remedial design to refine the delineation of work areas, and to understand whether changes have occurred in sediment bed concentrations due to shipping activities in the area of the SJRF operations (e.g., from propeller wash).

Following the general descriptions of alternatives provided in Sections 4.3 and 4.4 for the areas north and south of I-10, respectively, Section 5 provides a detailed evaluation of the remedial alternatives with consideration of criteria required by the NCP, 40 CFR Section 300.430(e)(9). Those criteria addressed include overall protection, compliance with ARARs, long-term effectiveness, reduction of toxicity, mobility or volume (TMV), short-term effectiveness, implementability and cost. Two additional criteria, State acceptance, and community acceptance, are not addressed. USEPA Region 6 Clean and Green Policy (USEPA 2009c) was also considered in the development of all of the alternatives.

4.3 Remedial Alternatives for the Area North of I-10

4.3.1 Alternative 1N – Armored Cap and Ongoing OMM (No Further Action)

This alternative serves as the baseline of comparison for the other remedial alternatives. The NCP requires the development and evaluation of a No Further Action alternative (40 CFR 300.430(e)(6)). As described in Section 2, the TCRA included capping the TCRA Site, selected stabilization of near surface soils in the Western Cell, installing a security fence, and posting warning signs. The Armored Cap was selected following a USEPA-approved TCRA alternatives evaluation, and was designed in accordance with USEPA and USACE cap design guidance (USACE 1998) to provide containment under a variety of storm conditions, up to the 100-year storm event specified by USEPA. It was constructed at a cost of $9 million, costs which are included in this and each of the other alternatives for the area north of I-10. In accordance with this guidance, an OMM plan was developed that was reviewed and approved by USEPA. Periodic inspections continue to be conducted to verify the integrity of the Armored Cap. The Armored Cap has been further enhanced in accordance with the recommendations made by USACE (USACE 2013). Additional details on the history of the design and monitoring of the Armored Cap are provided in Section 2.5.3.

Under this alternative, the controls installed as part of the TCRA and as a result of the TCRA reassessment would remain in place and no additional remedial action would be implemented. Since the TCRA remedy was a comprehensive and protective early action that successfully reduced dioxin/furan exposure within the TCRA Site area by more than 80 percent (Anchor QEA 2012b) and additional work to enhance the Armored Cap has since been completed, labeling Alternative 1N as the "No Action Alternative" is not accurate. However, under USEPA RI/FS (USEPA 1988), because TCRA construction was completed prior to the review of the array of potential remedies under the FS, the existing TCRA remedy for procedural purposes is designated as being the "No Action" alternative. However, under this "No Action" option, the Armored Cap would remain in place and would be subject to ongoing inspection and maintenance performed in accordance with the USEPA-approved OMM Plan.

In the area of the TCRA Site, the $TEQ_{DF,M}$ SWAC for soil/sediment following completion of the TCRA is approximately 12 ng/kg (Anchor QEA 2012b), which is well below the PRG for hypothetical recreational visitors (200 ng/kg). No surface soil/sediment samples outside the Armored Cap and within the Preliminary Site Perimeter have a $TEQ_{DF,M}$ concentration exceeding this PRG (Figure 3-1). The only sediment samples outside of the limits of the Armored Cap with $TEQ_{DF,M}$ concentrations exceeding the PRG for hypothetical recreational visitors are two subsurface sediment samples collected north of I-10 from one location (SJNE032, refer to Figure 2-4) near the Upland Sand Separation Area. These samples are buried beneath at least 3 feet of sediment with $TEQ_{DF,M}$ concentrations below the PRG.

This alternative includes ongoing OMM of the Armored Cap, which includes inspection and periodic maintenance, and USEPA 5-year reviews as required under the NCP in 40 CFR 300.430 (f)(iv)(2). The estimated cost of this alternative is $9.5 million (Appendix C).

4.3.2 Alternative 2N – Armored Cap, Institutional Controls and Monitored Natural Recovery

This alternative includes all of the elements discussed under Alternative 1N, plus ICs and MNR. Under this remedial alternative, the following ICs would be implemented:

- Restrictions on dredging and anchoring would be established to protect the integrity of the Armored Cap and to limit potential disturbance and resuspension of buried sediment near the Upland Sand Separation Area where one location exists with $TEQ_{DF,M}$ concentrations exceeding the sediment PRG.

- Public notices and signage around the perimeter of the TCRA Site would be maintained or provided, as appropriate.

A periodic sampling and analytical program would also be implemented to monitor the progress of natural recovery. Modeling, presented in Appendix A, projects that ongoing sedimentation will reduce $TEQ_{DF,M}$ concentrations in surface sediment over time. Specifically, natural recovery from sediment inputs within the USEPA's Preliminary Site Perimeter is predicted to further reduce the SWAC for 2,3,7,8-TCDD and 2,3,7,8-TCDF within the USEPA's Preliminary Site Perimeter by a factor of 2 over a period of 10- to 15-years. The estimated cost for this alternative is $10.3 million (Appendix C).

4.3.3 Alternative 3N – Permanent Cap, Institutional Controls and Monitored Natural Recovery

This alternative includes the actions described under Alternative 2N plus additional enhancements to the Armored Cap to create the Permanent Cap. This alternative will increase the long-term stability of the Armored Cap consistent with permanent isolation of impacted materials. Cost estimates for this alternative also include additional measures to protect the Permanent Cap from potential vessel traffic in the form of a protective perimeter barrier. In concept for this FS Report, these measures would include construction of a 5-foot high submerged rock berm outside the perimeter of the Permanent Cap, in areas where vessels could potentially impact the cap. This concept was prepared as an FS-level assumption and would be more fully developed during remedial design.

The Armored Cap was constructed to provide immediate containment of the materials in the TCRA Site. As required in USEPA's Action Memorandum for the TCRA (USEPA 2010a, Appendix A), the containment method was chosen to be compatible with the final remedy and meet applicable design criteria for degree of safety. As with any design, the degree of safety can be increased. For the Armored Cap, that would involve flattening the slopes of the existing Armored Cap by adding additional armor rock material to enhance the effectiveness and permanence of the Armored Cap remedy by increasing the degree of safety for the armor rock design, to create the Permanent Cap. Such measures are consistent with and exceed the recommendations made by USACE in its review of the Armored Cap performance (see Section 2), and will result in an enhanced cap that will be protective under worst-case storm and/or flood events.

The Armored Cap was originally designed with a robust armor layer to provide reliable containment of materials exceeding PRGs in the Northern Impoundments, as well as layers of geotextile and geomembrane. As described in Appendix B, armor materials were sized using a factor of safety of 1.3, which is greater than the suggested minimum factor of safety of 1.1 (USACE 1998) to provide additional protection of the Armored Cap against catastrophic failure. In January 2014, further enhancements were made to the Armored Cap in accordance with USACE recommendations (USACE 2013). To conduct the enhancement, the Respondents placed additional armor rock along the central and southern berms to flatten the slopes to 3 horizontal to 1 vertical (3H:1V), using rock sizes that meet or exceed USACE design criteria.

The Permanent Cap adds further robustness to the enhanced Armored Cap design by using an even higher factor of safety of 1.5 for sizing the armor stone, and by flattening submerged slopes from 2 horizontal to 1 vertical (2H:1V) to 3H:1V and flattening the slopes in the surf zone from 3H:1V to 5 horizontal to 1 vertical (5H:1V), including areas that were enhanced by the Respondents in January 2014. In addition, the Permanent Cap uses larger rock sized for the “No Displacement” design scenario, which is more conservative than the “Minor Displacement” scenario used in the Armored Cap’s design, and other CERCLA caps, such as Onondaga Lake and Fox River (Appendix B). Upon completion, the Permanent Cap will be constructed to a standard that exceeds USEPA and USACE design guidance, and meets or exceeds the recommended enhancements suggested by USACE in their 2013 evaluation of the Armored Cap.

The anticipated extent of the additional rock that would be placed during construction of a Permanent Cap is shown in Figures 4-1 and 4-2, and would entail construction of 5H:1V slopes along the central, western and southern berms, and 3H:1V slopes over the submerged portion of the Northwestern Area, requiring placement of approximately 3,400 cy of armor rock.

Based on the production rates that were realized during TCRA construction, the duration of construction for this alternative is estimated to be 2 months (Table 4-3). During construction of the TCRA, obtaining access to the work area from the uplands was a demonstrated implementability challenge; construction of Alternative 3N will require that access from the uplands be obtained, and obtaining such access could be a challenge. In addition, an off-site, river-side material staging area would be required to load the armor rock onto a barge for placement on the Armored Cap. There are limited river-side facilities upstream of the I-10 Bridge that can be accessed by heavy construction equipment. Because of the limited clearance height of the I-10 Bridge, downstream river-side facilities have the disadvantage that the size of equipment that can traverse between the work area and the off-site staging area would be limited by I-10 bridge clearance.

This alternative is estimated to require 750-hours of heavy equipment operations, resulting in greenhouse gas, PM, and ozone-generating emissions, and 260 truck trips causing greenhouse gas, PM, and ozone-generating emissions, as well as traffic impacts (Table 4-4). However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. Equipment and vehicle emissions of hydrocarbons and nitrogen oxides lead to the generation of smog, including ozone, which is a particular concern in Harris County which has been classified by USEPA as a "severe" non-attainment area for the 1997 8-hour ozone standard and a "moderate" non-attainment area for the 2008 8-hour ozone standard. Moreover, Harris County has not yet been classified for the 2012 fine particle particulate matter ($PM_{2.5}$) annual National Ambient Air Quality Standard (TCEQ 2013).

Using construction worker injuries and fatality rates published by the U.S. Department of Labor (USDL 2011), Alternative 3N is estimated to result in nearly 0.15 lost time injuries, and approximately 0.0006 fatalities as a result of construction (Table 4-5). Although both of these safety statistics are below 1.0, they are useful for comparison purposes to the safety-related issues of the other alternatives. Further discussion of this comparison is provided in Section 6. Worker safety issues would be addressed during remedial design, and measures would include, at a minimum, development of detailed health and safety plans to help mitigate these risks.

The cost of this alternative is estimated to be $12.5 million (Appendix C).

4.3.4 Alternative 4N – Partial Solidification/Stabilization, Permanent Cap, Institutional Controls and Monitored Natural Recovery

This remedial alternative provides for solidification and stabilization (S/S) of the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. The extent of the area for partial S/S was defined, based on sediment and soil chemistry results presented in the RI Report, as the Western Cell and a portion of the Eastern Cell of the TCRA Site that is currently covered by the Armored Cap. Based on the analysis of sediment core samples presented in Figure 2-4, the maximum depth of S/S in the Western Cell would be to approximately 10-feet below the current base of the Armored Cap and on average approximately 5-feet below the current base of the Armored Cap in the

Eastern Cell and Northwestern Area. A Permanent Cap, ICs, and MNR, as described in Sections 4.1.2 and 4.1.3, are also included in this remedial alternative.

Figure 4-3 presents a plan view of the partial S/S remedial alternative. Figure 4-4 presents a cross section of this remedial alternative to give a typical representation of the depth of S/S. S/S treatment could be accomplished using large-diameter augers or conventional excavators, similar to those that were used to treat portions of the sediment in the Western Cell during the TCRA. Both technologies are discussed in the RAM. Before treating the sediment, the affected portions of the Armored Cap armor rock would need to be removed and stockpiled for reuse, if possible, or washed to remove adhering sediment and disposed in an appropriate upland facility. The geotextile and geomembrane would need to be removed and disposed of as contaminated debris. S/S reagents, such as Portland cement, would be delivered to the project work area, stockpiled, and mixed with sediment, as needed, to treat the sediment in situ. Submerged areas to be stabilized would need to be isolated from the surface water with sheetpiling and mostly dewatered prior to mixing with treatment reagents using conventional or long reach excavators in a fashion similar to the S/S work completed during the TCRA. For FS purposes, a sheetpile enclosure with a top elevation 2-feet above typical mean higher high water, or 3.5-feet North American Vertical Datum of 1988 (NAVD88), has been assumed. Following completion of the S/S operation in submerged areas the sheetpile enclosure would be removed. Finally, the Permanent Cap, as described in Alternative 3N, would be constructed, including replacement of the armor rock layer geomembrane and geotextile over the S/S footprint, and the measures described in Section 4.3.3 to protect the Permanent Cap from vessel traffic would be implemented.

The estimated footprint of this alternative is approximately 2.6 acres in the Western Cell and 1.0 acre of submerged sediment spanning the Eastern Cell and the Northwestern Area (Figure 4-3). Based on the horizontal and vertical limits identified for this alternative, a total of approximately 52,000 cy of soil and sediment would be treated.

Using production rates similar to that achieved during the TCRA, this alternative has an estimated construction duration of 17 months (Table 4-3). As with Alternative 3N, access to the work area from the uplands will be required and could be a challenge, and an off-site staging area would be necessary to manage the materials generated during removal of the Armored Cap, and to stockpile and load the new armor rock materials to be placed for construction of the Permanent Cap. Compared to Alternative 3N, this off-site facility would need to be larger because of the need to manage the Armor Cap rock that is removed.
This alternative is estimated to require 5,450-hours of heavy equipment operations, and approximately 1,600 truck trips causing higher greenhouse gas, PM, and ozone-generating emissions and traffic impacts (Table 4-4) than the previous three alternatives. However,

there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10.

Alternative 4N is estimated to result in more than one lost time injury, and approximately 0.004 fatalities as a result of construction (Table 4-5). Worker safety issues would be addressed during remedial design, and measures would include, at a minimum, development of detailed health and safety plans to help mitigate these risks.

The cost of this alternative is estimated to be $23.2 million (Appendix C).

4.3.5 Alternative 5N – Partial Removal, Permanent Cap, Institutional Controls and Monitored Natural Recovery

This remedial alternative provides for removal of the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. The lateral and vertical extent and volume of sediment removed under this alternative is the same as the sediment to be treated as described in the previous section for Alternative 4N and is depicted on Figures 4-5 and 4-6. Construction of a Permanent Cap, ICs, and MNR, as described in Alternative 3N, are also included in this remedial alternative.

To mitigate potential water quality issues, submerged areas would need to be isolated using berms, sheet piles, and/or turbidity barrier/silt curtains prior to excavating sediment. Upland areas would not need to be isolated with sheetpiling, but the excavation would require continuous dewatering and may need to be timed to try to avoid high water and times of year when storms are most likely.

Excavated sediment would be dewatered and potentially treated to eliminate free liquids prior to transporting it for disposal. Effluent from excavated sediment dewatering would need to be handled appropriately, potentially including treatment prior to disposal. Following completion of the excavation, the work area would be backfilled to replace the excavated sediment and then the Permanent Cap would be constructed, including replacing the armor rock layer above the excavation footprint and the geomembrane and geotextile layers.

The construction duration for this alternative is estimated to be 13 months (Table 4-3). This alternative is estimated to require almost 7,000-hours of heavy equipment operations and more than 9,300 truck trips causing higher greenhouse gas and PM, ozone generating emission, and traffic impacts (Table 4-4) as compared to the previous four alternatives.

As with Alternatives 3N and 4N, access to the work area from the uplands will be required and could be a challenge. An off-site facility would need to be identified and secured to manage dredged materials (including dewatering, transloading, and shipping) and to stockpile and load imported armor rock. Given the nature of the material being managed at the facility, locating a suitable property and willing landowner could be difficult.

Off-site transport of materials for disposal presents a risk for spills and accidents, which could result in exposure of these materials to the general public. Alternative 5N is estimated to result, on average, in more than 1 non-fatal lost time injury, and approximately 0.006 fatalities as a result of construction (Table 4-5). Worker safety issues would be addressed during remedial design, and measures would include, at a minimum, development of detailed health and safety plans to help mitigate these risks.

The cost of this alternative is estimated to be $38.1 million (Appendix C).

4.3.6 Alternative 5aN – Partial Removal of Materials Exceeding the PRG, Permanent Cap, Institutional Controls and Monitored Natural Recovery

For this removal alternative, the PRG for hypothetical recreational visitor (200 ng/kg $TEQ_{DF,M}$) was considered for the area within the Armored Cap which is either above the water or where the water depth is 10 feet or less. As an additional criterion, locations exceeding 13,000 ng/kg $TEQ_{DF,M}$ are also included regardless of water depth; however, all samples exceeding 13,000 ng/kg $TEQ_{DF,M}$ are located in areas where the water depth is 10 feet or less.

The lateral and vertical extents of the removal under this remedial alternative are presented in Figures 4-7 and 4-8. As with the Alternatives 4N and 5N, the existing Armored Cap (consisting of cap rock, geomembrane and geotextile) which currently isolates and contains impacted material would need to be removed prior to beginning excavation work.

This alternative also includes an engineered barrier to manage water quality during construction. In shallow water areas (water depths up to approximately 3 feet), this barrier would be constructed as an earthen berm, extending to an elevation at least 2 feet above the high water elevation in consideration of wind-generated waves and vessel wakes. The berm would be limited to a total height of 4 to 5 feet above the existing mudline for constructability reasons: as the berm height increases, the base width increases and it can be challenging to efficiently construct taller berms because they become wider at their base than the reach of a typical excavator. In areas with water depths deeper than about 3 feet, the berm would transition into a sheetpile barrier around the work area. Figure 4-7 depicts the approximate limits where the earthen berm and sheetpile barriers could potentially be constructed.

Work would be conducted in the wet. Excavated sediment would be offloaded, dewatered and stabilized at a dedicated offloading location, as necessary, to eliminate free liquids for transportation and disposal. Following removal of impacted sediment, the area from which sediments are removed would be covered with a residuals management layer of clean cover material. In the deeper water areas of the TCRA Site where removal is not conducted, the existing Armored Cap would be maintained.

This alternative entails removal of approximately 137,600 cy of sediment from the TCRA Site, which would require a relatively large offloading and sediment processing facility to efficiently accomplish the work. As with Alternative 5N, the challenges with locating such a facility could be significant and are magnified because a larger site would potentially be needed to manage the greater volume of dredged material (including dewatering, transloading, and shipping) and to stockpile and load imported armor rock. Alternative 5aN is estimated to have a construction duration of 19 months (Table 4-3).

Installation of a sheetpile containment is expected to pose a implementability challenge due to the relatively shallow water (limiting the size of barge-mounted pile-driving equipment that can be used), and challenges that have been experienced on other projects where sheetpile barriers were used (See Section 4.1.4).

This alternative is estimated to require approximately 15,665 hours of heavy equipment operations and over 12,855 truck trips, resulting in higher greenhouse gas and PM, ozone generating emissions, and traffic impacts (Table 4-4) as compared to the previous five alternatives. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. Off-site transport of materials for disposal presents a higher risk for spills and accidents compared to Alternative 5N, which could result in exposure of these materials to the general public. Using an additive drying amendment such as lime or Portland cement could result in fugitive dust emissions at the offloading/processing area, however measures would be implemented to control dust.

Alternative 5aN is estimated to result in approximately 3 lost time non-fatal injuries, and approximately 0.01 fatalities as a result of construction (Table 4-5). Worker safety issues would be addressed during remedial design, and measures would include, at a minimum, development of detailed health and safety plans to help mitigate these risks.

The cost of this alternative is estimated to be $77.9 million (Appendix C).

4.3.7 Alternative 6N – Full Removal of Materials Exceeding the PRG, Institutional Controls and Monitored Natural Recovery

For the full removal alternative, the hypothetical recreational visitor exposure scenario was considered for area north of I-10. The PRG for protection of the hypothetical recreational visitor is a $TEQ_{DF,M}$ concentration of 200 ng/kg.

The lateral and vertical extents of the removal under this remedial alternative are presented in Figures 4-9 and 4-10. The work area would be isolated with berms, sheet piles, and/or with turbidity barrier/silt curtains. As with the partial removal alternatives, cap rock, geomembrane and geotextile from the existing Armored Cap, which currently isolates and contains impacted material, would need to be removed prior to beginning excavation within the TCRA Site. Similarly, upland excavation could require dewatering to allow excavation of impacted sediment in relatively dry conditions, and excavation of submerged sediment would require isolation of the work area with a turbidity barrier/silt curtain. Excavated sediment would be further dewatered and stabilized at the offloading location, as necessary, to eliminate free liquids for transportation and disposal. Some operations, such as water treatment, could be barge mounted. Following removal of impacted sediment, the area from which sediments are removed would be covered with two residuals management layers of clean sediment to reduce intermixing.

This alternative entails removal of approximately 200,100 cy of sediment from the TCRA footprint and the area near the Upland Sand Separation Area, which would require a relatively large offloading and sediment processing facility to efficiently accomplish the work, which would require barge unloading, sediment re-handling, dewatering, stockpiling, transloading, and shipping to the off-site landfill facility. Additional activities would include management and disposal of dewatering effluent, including treatment if necessary.

Alternative 6N is estimated to have a construction duration of 16 months (Table 4-3). Similar to the issues described for Alternatives 5N and 5aN, locating an adjacent facility with sufficient space and availability for more than a year of use for staging, offloading, and sediment processing is considered to be a challenge to the implementability of Alternative 6N.

This alternative is estimated to require approximately 15,500 hours of heavy equipment operations and approximately 17,500 truck trips, resulting in higher greenhouse gas and PM, ozone generating emissions, and traffic impacts (Table 4-4) as compared to the Alternatives 1N through 5N. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. Off-site transport of materials for disposal presents a higher risk for spills and accidents compared to Alternative 5N, which could result in exposure of these materials to the general public. Using an additive drying amendment such as lime or Portland cement could result in fugitive dust emissions at the offloading/processing area, however, measures would be implemented to control dust.

Alternative 6N is estimated to result in more than 3 lost time non-fatal injuries, and approximately 0.01 fatalities as a result of construction (Table 4-5). Worker safety issues would be addressed during remedial design, and measures would include, at a minimum, development of detailed health and safety plans to help mitigate these risks.

The cost of this alternative is approximately $99.2 million (Appendix C).

4.4 Remedial Alternatives for the Area South of I-10

4.4.1 Alternative 1S – No Further Action

This alternative serves as the baseline of comparison for the other remedial alternatives. The NCP requires the development and evaluation of this alternative (40 CFR 300.430(e)(6)). Under this remedial alternative for the area of investigation south of I-10, impacted soil would remain in place and no steps would be taken to alert future landowners or construction workers of the presence, at depth, of $TEQ_{DF,M}$ concentrations exceeding the PRG.

The estimated cost for this alternative, which includes future USEPA 5-year review costs, is $140,000. These USEPA 5-year review costs are also included in cost estimates for the other alternatives.

4.4.2 Alternative 2S – Institutional Controls

The PRG for the hypothetical future construction worker is based on exposure assumptions that include contact with the soil interval from the surface to 10 feet below grade. Therefore, the PRG should be compared to the average soil concentration in the top 10-feet of soil, which is how the data are presented in Figure 3-5.

The BHHRA (Integral 2013b) concluded that there are no unacceptable risks associated with surface soil (soil from 0 to 6 inches below ground surface). The arithmetic mean of $TEQ_{DF,M}$ concentrations in surface soil is 13.3 ng/kg, which is well below the PRG for a hypothetical outdoor commercial worker (750 ng/kg). The highest $TEQ_{DF,M}$ concentration observed in surface soil, 36.9 ng/kg (SJSB023, refer to Figure 2-5), is also well below this PRG.

This alternative would apply to locations in the area south of I-10 where the average $TEQ_{DF,M}$ concentration in the upper 10-feet of soil below grade exceeds the PRG for the hypothetical future construction worker (240 ng/kg). $TEQ_{DF,M}$ concentrations in the upper 10-feet of soil exceed the PRG at four locations (SJSB012, SJSB019, SJSB023, and SJSB025) shown in Figure 3-5.

Under this remedial alternative, the following ICs would be implemented:

- Deed restrictions would be applied parcels in which the depth-weighted average $TEQ_{DF,M}$ concentrations in upper 10-feet of subsurface soil exceed the soil PRG for the hypothetical future construction worker (Figure 4-11).

- Notices would be attached to deeds of affected properties to alert potential future purchasers of the presence of waste and soil with $TEQ_{DF,M}$ concentrations exceeding the soil PRG.

The estimated cost for this remedial alternative is $270,000 (Appendix C).

4.4.3 Alternative 3S – Enhanced Institutional Controls

This remedial alternative would incorporate the ICs identified in Section 4.4.2 and add physical features to enhance the effectiveness of the ICs. The physical features would include bollards to define the areal extent of the remedial action areas at the surface and a marker layer that would alert workers digging in the area that deeper soil may be impacted. Figure 4-11 shows the locations of the remedial action areas south of I-10.

Implementation of this remedial alternative may include the following steps:

- Removing up to 2 feet of surface soil.

- Temporarily stockpiling the soil on-site.

- Placing the marker layer (such as a geogrid or similar durable and readily visible material) at the bottom of the excavation.

- Returning the soil to the excavation and re-establishing vegetative cover.
- Placing bollards at the corners of the remedial action areas.

The duration of construction for this remedial alternative is estimated to be 1 month (Table 4-6). This alternative is estimated to require approximately 160 hours of heavy equipment operations, resulting in greenhouse gas, PM, and ozone-generating emissions (Table 4-7). However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. Alternative 3S is estimated to result in 0.015 lost time injury and 0.0001 fatalities as a result of construction (Table 4-8). The estimated cost for this remedial alternative is $9.5 million (Appendix C).

4.4.4 Alternative 4S – Removal and Off-site Disposal

This remedial alternative involves excavation and replacement of soil in the three remedial action areas shown in Figure 4-11. Soil would be removed within these areas to a depth of 10 feet below grade. Implementation of this remedial alternative would require dewatering (groundwater lowering) to allow excavation of impacted soil in relatively dry conditions and may need to be timed to try to avoid high water and periods when storms are most likely. Excavated soil would be further dewatered, as necessary, and potentially treated to eliminate free liquids prior to transporting it for disposal. Effluent from excavation and subsequent dewatering would need to be handled appropriately, potentially including treatment prior to disposal. Excavated soil would be disposed of at an existing permitted landfill, the excavation would be backfilled with imported soil, and vegetation would be re-established. Pavement on Market Street adjacent to Remedial Action Area South 1 (Figure 4-11) would be repaired.

An existing building (an elevated frame structure) and a concrete slab within Remedial Action Area South 3 (Figure 4-11) would need to be demolished and removed prior to excavating the underlying soil. These features would be replaced, if necessary.

The removal volume (50,000 cy) was calculated assuming a conservative excavation side slope of 2 horizontal to 1 vertical. Transportation and disposal costs were estimated assuming that all of the excavated material would be transported to a licensed landfill for disposal. During remedial design, potential cost savings associated with segregating clean soil and using it as backfill may be explored.

Appropriate containment and controls for dust and runoff would be provided for any soil stockpiles or soil amendment areas that may be required. Trucks would be inspected and decontaminated, as necessary, before they would be released from the site to avoid tracking soil from the work site onto public roads.

The duration of construction for this remedial alternative is estimated to be 7 months (Table 4-6). This alternative is estimated to require approximately 900 hours of heavy equipment operations and more than 7,000 truck trips, resulting in greenhouse gas and PM, and ozone-generating emissions (Table 4-7). However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. Alternative 4S is estimated to result in 0.088 lost time injury and 0.0004 fatalities as a result of construction (Table 4-8). The estimated cost for this remedial alternative is $9.9 million (Appendix C).

5 DETAILED ANALYSIS OF REMEDIAL ALTERNATIVES

As discussed in Section 4, the detailed evaluation of remedial alternatives is based on consideration of the following criteria, as required by the NCP, 40 CFR Section 300.430(e)(9):

1. Overall protectiveness of human health and the environment
2. Compliance with ARARs
3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility or volume through treatment
5. Short-term effectiveness
6. Implementability
7. Cost
8. State/Support Agency acceptance
9. Community acceptance

The first two criteria, overall protectiveness and compliance with ARARs, are identified as threshold criteria in 40 CFR Section 300.430(f). Remedial alternatives must satisfy the threshold criteria to be selected as the final remedy, although ARAR waivers are considered in some circumstances. The next five criteria are identified as primary balancing criteria. The comparative analysis considers the anticipated performance of the remedial alternatives relative to these balancing criteria. The final two criteria, identified as modifying criteria, are considered by USEPA in preparing the ROD based on consultation with the State environmental agency and public comments received in response to the FS Report and the proposed plan. Item 39 of the Statement of Work attached to the UAO states that the modifying criteria are not to be considered in the comparative analysis in this FS Report. Information related to the modifying criteria are therefore not provided in this section.

The first seven criteria, as presented in 40 CFR 300.430(f), are briefly defined below:

- *Overall protectiveness of human health and the environment* is an evaluation of whether the remedial alternative can adequately protect human health and the environment. This may be expressed as an assessment of whether the remedial alternative addresses all of the RAOs, which are identified and described in Section 2.

- *Compliance with ARARs* is an evaluation of whether the remedial alternative addresses or can be implemented in compliance with all of the ARARs, which are identified in Table 3-1. Section 121 (d) of CERCLA and NCP §300.430(f)(1)(ii)(B) require that remedial actions at CERCLA sites at least attain legally applicable or relevant and appropriate Federal and State requirements, standards, criteria, limitations which are collectively referred to as "ARARs," unless such ARARs are waived under CERCLA section 121(d)(4) and NCP §300.430(f)(1)(ii)(C).

- *Long-term effectiveness and permanence* is an evaluation of the ability of the remedial alternative to reliably maintain protection of receptors.

- *Reduction of toxicity, mobility or volume through treatment* is an evaluation of the degree to which treatment or recycling of affected media is used to reduce the TMV of contaminated media, particularly principal threats.

- *Short-term effectiveness* is an evaluation of both the time required for the remedial alternative to achieve full protection and the degree to which potential risk to human health and the environment is increased during implementation of the remedy, considering measures that may be used to mitigate short-term risks until cleanup levels are achieved. The short-term effectiveness evaluation also includes an evaluation of the sustainability of the remedial alternative in conformance with the USEPA Region 6 Clean and Green Policy (USEPA 2009c).

- *Implementability* is an evaluation of the technical and administrative feasibility of a remedy from design through construction and operation. Factors such as availability of services and materials, administrative feasibility, and coordination with other governmental entities are also considered. Technical factors include consideration of whether the remedial alternative involves the use of well demonstrated technologies, readily available equipment and materials, and whether any physical conditions of the project work area may impede implementation. Administrative factors include consideration of whether implementation of the remedial alternative might be impeded by the need to obtain approvals from nearby landowners or public agencies.

- *Cost* is an evaluation of construction and long-term operation, maintenance, and monitoring costs. A present-worth cost analysis is typically used to evaluate the total cost of remedial alternatives. Both CERCLA and the NCP, require that remedies be cost-effective (42 U.S. Code [U.S.C.] §9621(a); 40 CFR §300.430(f)(1)(ii)(D)): "Each remedial action selected shall be cost-effective" (40 CFR §300.430(f)(1)(ii)(D)). Cost-effectiveness is defined as "costs are proportional to its overall effectiveness." (40 CFR §300.430(f)(1)(ii)(D)). Pursuant to the USEPA's 1999 guidance, A Guide to Preparing Proposed Plans, Records of Decision, and Other Remedy Selection Documents, "cost-effectiveness is concerned with the reasonableness of the relationship between the effectiveness afforded by each alternative and its costs compared to other available options." Moreover, "if the difference in effectiveness is small but the difference in cost is very large, a proportional relationship between the alternatives does not exist" (Federal Register 1990). These proportionality requirements were reiterated by USEPA in the above-cited guidance.

This section describes the individual analyses for each of the alternatives for the areas north and south of I-10. Table 5-1 summarizes the key discussion points from this section for each of the evaluation criteria for area north of I-10. Table 5-2 summarizes the same information for the area south of I-10.

5.1 Area North of I-10

5.1.1 Alternative 1N – Armored Cap and Ongoing OMM (No Further Action)

5.1.1.1 Overall Protection of Human Health and the Environment

This remedial alternative (which includes the Armored Cap and continued OMM of the Armored Cap) is protective of human health and the environment. As discussed in Section 2.5, for the area north of I-10 the TCRA resulted in capping and isolation of all sediment samples with $TEQ_{DF,M}$ concentrations exceeding the applicable PRGs, except for those located within a small area of subsurface sediment near the Upland Sand Separation Area (located to the west of the TCRA Site). Based on data from the RI study, the subsurface sediment near the Upland Sand Separation Area is isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PRG for hypothetical recreational visitors.

5.1.1.2 Compliance with ARARs

Alternative 1N would not result in construction impacts or other changes to baseline conditions that would trigger any action-, chemical-, or location-specific ARARs identified in Table 3-1. The fate and transport model described in Appendix A predicts improvements in water quality within the USEPA's Preliminary Site Perimeter as a result of the Armored Cap construction. Under these post-TCRA conditions, there are no documented exceedances of surface water quality standards within the USEPA's Preliminary Site Perimeter due to the presence of dioxins and furans, even though there are ongoing external sources of dioxins and furans from atmospheric deposition, upstream sediment loads, stormwater runoff and point source discharges. Therefore, the continuation of post-TCRA conditions is expected to result in ongoing water quality compliance. Because no construction activity is included in this alternative, there are no substantive permit conditions that would need to be met.

5.1.1.3 Long-Term Effectiveness

Alternative 1N would not affect long-term residual risks nor would it affect or enhance the reliability of existing controls. The long-term effectiveness of this remedial alternative was evaluated considering the potential for natural forces or human activity to expose the sediment or soil with $TEQ_{DF,M}$ concentrations that exceed the applicable PRGs. The sediment transport modeling (Appendix A) results indicate that sediment in the vicinity of the Upland Sand Separation Area is stable and net sedimentation in this area is expected to provide continued isolation at this buried location; however, propeller wash from tug boat operations could disturb these sediments. The Armored Cap isolates sediment within the TCRA Site except for one known instance (December 2015) from potential receptors and has been designed to resist erosive forces during 100-year return period flood events in the San Jacinto River. However, cap repairs were necessary in 2013, 2015, and in 2016 due to inadequate or missing armor rock cover in relatively small areas. No flood since the cap was constructed in 2011 has exceeded a 100-year return period design flood, nor is there any instance of exceeding a 10-year flood.

Work implementing USACE recommendations to enhance the cap's long-term stability was completed in January 2014. This remedial alternative does not include alerting future landowners of the TCRA Site to the potential risks associated with activities that may involve exposing the capped sediment, and does not include placing restrictions on dredging or anchoring at the TCRA Site. The protection provided by the Armored Cap would be continued through long-term monitoring and maintenance, which will be required for as long as the dioxin/furan represents an unacceptable risk should exposure occur. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. Dioxins and furans are persistent contaminates that will not readily break down. While there is much uncertainty regarding how long the waste materials will represent an unacceptable risk should exposure occur, but by one estimate approximately 750 years would be required for the waste to break down to the PRG level.

5.1.1.4 Reduction of Toxicity, Mobility or Volume

Alternative 1N would not include additional reduction of TMV through treatment. However, it is important to note that sediment in the Western Cell was treated with Portland cement during the TCRA reducing the mobility of impacted sediment. Model predictions presented in Appendix A indicate that net erosion depths during extreme flood events will be limited to less than 15 centimeters in this area. However, there is uncertainty in the model results as evidenced by the model predicted erosion south of the I-10 Bridge that was much less than the approximately 10-feet of scour that actually occurred there during the 1994 storm. Over the long-term, ongoing deposition may result in declines in surface sediment concentrations. Natural deposition is expected to cover the site; however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion that was documented during the 1994 flood, then the predicted deposition may not occur.

In addition, disturbance from propeller wash due to activities from barge operations in the San Jacinto River could cause locally greater erosion than that modeled during flood events depending on the water depth, the size of the vessel, and the duration of vessel operations. Such disturbance could cause changes in concentration of $TEQ_{DF,M}$ in the area of erosion and its vicinity. Sediment in the footprint of the Armored Cap is generally isolated from exposure at the surface by layers of geotextile, geomembrane, and cap rock except for areas in the underwater portions of the northwest part of the cap, for example, that do not contain geotextile or geomembrane.

5.1.1.5 Short-Term Effectiveness

There are no short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative.

5.1.1.6 Implementability

There are no technical or administrative implementability issues associated with this remedial alternative. Monitoring the Armored Cap, which is required under the USEPA-approved OMM Plan and is part of this remedial alternative, should not pose implementability challenges.

5.1.1.7 Cost

The estimated cost associated with this remedial alternative is $9.5 million (Appendix C) for Armored Cap construction and for implementing the existing OMM Plan for the Armored Cap, signs, buoys and fencing. Costs include monitoring, maintenance events, and USEPA 5-year reviews as described in Appendix C, and are based on access to the TCRA Site being available from the river and through the TxDOT right-of-way (ROW). Long term monitoring events will be required for as long as an unacceptable risk from the dioxin/furan remain.

5.1.2 Alternative 2N – Armored Cap, Institutional Controls and Monitored Natural Recovery

5.1.2.1 Overall Protection of Human Health and the Environment

This remedial alternative would achieve the RAOs through a combination of ICs, MNR, and existing engineering controls. As noted in Section 5.1.1, the Armored Cap is protective of human health and the environment. Sediment with $TEQ_{DF,M}$ concentrations exceeding the applicable PRGs are isolated from potential receptors by the Armored Cap or by sediment with $TEQ_{DF,M}$ concentrations below the PRGs. ICs would be used to:

- Alert property owners of the presence of subsurface materials exceeding PRGs.

- Describe the need for protective equipment and training if excavation of subsurface materials exceeding PRGs is required in the TCRA footprint.

- Describe requirements for the management of any excavated soil or sediment exceeding PRGs.

- Describe the need to restore the Armored Cap following any disturbance.

- Establish limitations on dredging and anchoring within the footprint of the Armored Cap by requesting, in accordance with 33 CFR 165.5, that the U.S. Coast Guard District Commander establish a regulated navigation area.

Affected sediment near the Upland Sand Separation Area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PRG, would be further isolated by deposition of additional sediment through ongoing natural recovery processes as described in Section 2.6 and Appendix A. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. Monitoring of sediment conditions in this area would be performed to confirm that deposition of new sediment was continuing to maintain surface $TEQ_{DF,M}$ concentrations below the PRG for hypothetical recreational visitors. The MNR plan would include methods for assessing whether deposition or erosion were occurring at monitoring stations between monitoring events. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. The actual scope and timeline of monitoring would be determined in coordination with USEPA during remedial design and during implementation of the monitoring program over the years.

5.1.2.2 Compliance with ARARs

Alternative 2N would involve a minimal amount of physical activity for the implementation of ICs (e.g., landowner notifications; restrictions on dredging and anchoring) and ongoing implementation of existing engineering controls. For the same reasons presented in the ARAR compliance discussion under Alternative 1N (Section 5.1.1.2), due to the minimal amount of active construction involved, Alternative 2N is also expected to generally meet the substantive requirements of the ARARs presented in Section 3.4.

5.1.2.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative is primarily derived from the Armored Cap and the ICs that would protect the integrity of the Armored Cap. Long-term effectiveness is also provided by the layers of surface soil and sediments with concentrations below PRGs and the monitoring that would confirm the continued deposition of clean sediment isolating the affected sediment outside of the footprint of the Armored Cap. Long-term simulations conducted with the fate and transport model indicate the surface sediment concentrations averaged over the USEPA's Preliminary Site Perimeter are predicted to decline by a factor of 2 over an approximate 10- to 15-year time period (see Appendix A); monitoring would be conducted to verify actual reductions in sediment concentrations. The highest $TEQ_{DF,M}$ concentrations within the USEPA's Preliminary Site Perimeter—in the footprint of the Armored Cap—are already isolated from potential receptors by the Armored Cap, with one exception. Since construction of the cap in 2011, the cap isolated sediment within the TCRA Site except for one known instance (December 2015) from potential receptors and has been designed to resist erosive forces during 100-year return period flood events in the San Jacinto River. However, cap repairs were necessary in 2013, 2015, and in 2016 due to inadequate or missing armor rock cover in relatively small areas. No flood since the cap was constructed in 2011 has exceeded a 100-year return period design flood.

Risk reduction is achieved by the Armored Cap and the clean soil and sediment layers, which protect against exposure through the applicable potential pathways, and by the use of ICs and monitoring to verify that the isolation layers remain effective. Monitoring and maintenance be required for as long as the dioxin/furan represents an unacceptable risk should exposure occur. Dioxins and furans are persistent contaminates that will not readily break down. While there is much uncertainty regarding how long the waste materials will represent an unacceptable risk should exposure occur, but by one estimate approximately 750 years would be required for the waste to break down to the PRG level.

5.1.2.4 Reduction of Toxicity, Mobility or Volume

There is no additional reduction of TMV due to treatment associated with this remedial alternative beyond that which was achieved during the TCRA. As noted in Section 5.1.1.4, sediments were treated during the TCRA, contributing to the reduction of mobility.

5.1.2.5 Short-Term Effectiveness

There are no short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative. The remedy would achieve full protection in the TCRA Site immediately. As additional clean sediment continues to be deposited in aquatic areas within the USEPA's Preliminary Site Perimeter, $TEQ_{DF,M}$ concentrations in the near surface sediment interval may continue to decline and the buried sediment near the Upland Sand Separation Area with $TEQ_{DF,M}$ concentrations exceeding the PRG may be further isolated from potential receptors. Ongoing deposition may result in declines in surface sediment concentrations, however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion similar to that which was documented during the 1994 flood, then the predicted deposition may not occur.

5.1.2.6 Implementability

There are no technical implementability issues associated with this remedial alternative. Alternative 2N would involve a minimal amount of physical activity for the implementation of ICs (e.g., landowner notifications; restrictions on dredging and anchoring) and on-going implementation of existing engineering controls. Monitoring would involve collecting and analyzing sediment samples and evaluating the data, which are routine procedures for qualified environmental consultants and laboratories. Establishing ICs is routine; there are no anticipated administrative implementability issues associated with this remedial alternative.

5.1.2.7 Cost

The estimated present worth cost associated with this remedial alternative is $10.3 million (Appendix C). The capital costs for this remedial alternative are associated with preparation of sampling plans, deed restrictions and notices, and a soil management plan. The long-term costs are for collecting and analyzing environmental samples, evaluating the data, preparing reports to document MNR, conduct of 5-year reviews by USEPA, and future monitoring and maintenance of the Armored Cap, as described in Appendix C. The cost estimate for this alternative assumes available access to the TCRA Site by water from a location along the river and by land through the TxDOT ROW. It is understood that the actual number of monitoring events will be subject to further discussion with and approval by USEPA.

5.1.3 Alternative 3N – Permanent Cap, Institutional Controls and Monitored Natural Recovery

5.1.3.1 Overall Protection of Human Health and the Environment

This remedial alternative would achieve the RAOs through a combination of active remedial construction, monitoring and cap maintenance, MNR addressing additional sediment deposition and implementation of ICs Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data.

The active component will include construction of further enhancements to the Armored Cap, even beyond the approved and protective Armored Cap constructed in 2011 and the enhancement work performed in January 2014. Additional enhancements will include adding additional armor rock to the cap, which will further flatten the slopes, and measures to construct a protective perimeter barrier to protect the Permanent Cap from vessel traffic. The Permanent Cap would be designed to be protective under a 500 year flood event, and meet or exceed USACE and USEPA cap design criteria. The alternative includes, in concept, the construction of a submerged rock berm as the protective perimeter barrier. Cap monitoring, inspections and maintenance, as needed, would be incorporated into the final remedy to ensure the long-term effectiveness of the remedy.

MNR would address the affected sediment near the Upland Sand Separation Area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PRG and would be further isolated by deposition of additional clean sediment as described in Section 2.5 and Appendix A.

For purposes of MNR, monitoring of sediment conditions in this area would be performed to confirm that deposition of new sediment was continuing to maintain $TEQ_{DF,M}$ concentrations in surface sediments below the PRG for protection of hypothetical recreational visitors. The MNR plan would include methods for assessing whether deposition or erosion were occurring at monitoring stations between monitoring events. The actual scope and timeline of monitoring would be determined in coordination with USEPA during remedial design.

ICs would be used to:

- Alert property owners of the presence of subsurface materials exceeding PRGs
- Describe the need for protective equipment and training if excavation of subsurface materials exceeding PRGs is required in the footprint of the Permanent Cap
- Describe requirements for the management of any excavated soil or sediment exceeding PRGs
- Describe the need to restore the cap or clean cover soil in these areas following any disturbance
- Establish limitations on dredging and anchoring within the footprint of the Permanent Cap by requesting, in accordance with 33 CFR 165.5, that the U.S. Coast Guard District Commander establish a regulated navigation area.

5.1.3.2 Compliance with ARARs

Implementation of Alternative 3N would involve the placement of fill material (the additional armor rock) into the San Jacinto River to create the Permanent Cap. The placement of fill would trigger compliance with CWA Section 404(b)(1) and potentially other ARARs related to surface water quality standards. However, Alternative 3N is expected to generally meet the substantive requirements of the ARARs in Table 3-1 through implementation of the BMPs and the agency coordination actions outlined in Section 3.4. Construction of the Permanent Cap would require the placement of approximately 3,400 cy of additional cap armor rock material. Hydrodynamic modeling was performed to confirm that the placement of the additional armor rock would not significantly affect flood-storage capacity in the San Jacinto River (Appendix B). Based on the results of this modeling, the long-term change to the maximum water surface elevation following placement of the additional armor rock under this alternative is estimated to be -0.01 to -0.02 feet, which is an indication that the effect of rock placement is negligible and immeasurable within the predictive capability of the flood model.

5.1.3.3 Long-Term Effectiveness

The long-term effectiveness of the existing Armored Cap in this alternative is enhanced by adding armor rock to the cap and flattening the slopes of the cap. Flattening the slopes to create the Permanent Cap, as shown in Figures 4-1 and 4-2, would further enhance the structural integrity and long-term reliability of the cap. Surface flow and wave break modeling, described in more detail in Appendix B, was performed to evaluate potential erosive forces associated with a variety of storms and extreme flow events. The results of the modeling were used to confirm that the rock selected for the cap would further resist movement and provide reliable, and enhanced long-term containment of material beneath the Permanent Cap. The armor rock that will be used to create the Permanent Cap will meet or exceed sediment cap design guidance and the recommendations made by USACE in its review of the TCRA design and construction, and a protective perimeter barrier would further increase the long-term effectiveness of the Permanent Cap by protecting the cap from vessel traffic. This alternative is also effective over the long-term because of declines in sediment surface concentrations due to natural recovery (Appendix A) throughout USEPA's Preliminary Site Perimeter. Ongoing deposition may result in declines in surface sediment concentrations, however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion that was documented during the 1994 flood, then the predicted deposition may not occur. Monitoring would confirm the continued deposition of new sediment isolating the affected sediment outside of the footprint of the Armored Cap.

Since construction of the cap in 2011, the cap isolated sediment within the TCRA Site except for one known instance (December 2015) from potential receptors and has been designed to resist erosive forces during 100-year return period flood events in the San Jacinto River. However, cap repairs were necessary in 2013, 2015, and in 2016 due to inadequate or missing armor rock cover in relatively small areas. No flood since the cap was constructed in 2011 has exceeded a 100-year return period design flood.

Monitoring and maintenance be required for as long as the dioxin/furan represents an unacceptable risk should exposure occur. Dioxins and furans are persistent contaminates that will not readily break down. While there is much uncertainty regarding how long the waste materials will represent an unacceptable risk should exposure occur, but by one estimate approximately 750 years would be required for the waste to break down to the PRG level.

5.1.3.4 Reduction of Toxicity, Mobility or Volume

There is no additional reduction of TMV due to treatment associated with this remedial alternative beyond that achieved during the TCRA. However, some of the impacted sediments at the Site, found in the Western Cell, were treated and mobility reduced via S/S during the TCRA. Risk reduction is further achieved by the construction of the Permanent Cap, the clean soil and sediment layers interrupting potential exposure pathways at locations outside the Permanent Cap, and by the use of ICs and monitoring to verify that the isolation layers remain effective.

5.1.3.5 Short-Term Effectiveness

Short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative are limited to minimal turbidity associated with placement of armor rock, potential accidents during construction of the Permanent Cap, air emissions from construction equipment, and truck traffic in the community. The evaluation of air emissions and truck traffic was conducted to provide a comparative basis from which to understand the relative impact of construction for each remedial action. It is acknowledged that there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the TCRA Site, and the presence of I-10.

Because of the limited duration of construction for this alternative (2 months), these risks are considered to be low. As compared to Alternatives 4N, 5N, 5aN, and 6N, this alternative is also estimated to require the fewest truck trips (260) during construction (Table 4-4). The short duration of construction is correlated with relatively low greenhouse gas, PM, and ozone-generating emissions from the construction equipment (Table 4-4). Water quality impacts from turbidity associated with placing the new armor rock are also low for this alternative because the armor rock fines that would create the turbidity would be from the rock acquired for the project and therefore not be chemically impacted. Further, risks of impacts due to storm events during construction are considered negligible because implementation does not require removing the existing Armored Cap to complete the work, and there are no rigid barriers that could restrict flow during potential flood events.

Finally, because construction work, and in particular over-water work, presents a higher risk of accidental injury or death to workers, the limited duration of this alternative results in a relatively low safety risk (Table 4-5). The remedy, like Alternatives 1N and 2N, would achieve full protection within the TCRA Site upon completion of construction. As additional sediment continues to be deposited within the USEPA's Preliminary Site Perimeter, $TEQ_{DF,M}$ concentrations in surface sediments would continue to decline to background levels (Appendix A) and the buried sediment near the Upland Sand Separation Area with $TEQ_{DF,M}$ concentrations exceeding the PRG would be further isolated from potential receptors.

5.1.3.6 Implementability

There are limited implementability concerns associated with this remedial alternative. Construction of the Permanent Cap will require the placement of additional cap material on underwater slopes. The feasibility of this construction technique was successfully demonstrated during the TCRA construction, and experienced local contractors are available to complete this work. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data, which are routine procedures for qualified environmental consultants and laboratories. Establishing ICs is fairly routine, so no administrative implementability issues are anticipated to be associated with this remedial alternative.

Technical implementability issues include obtaining access to the project work area, limited availability of off-site locations for staging, material management, and barge access, and the low clearance under the I-10 Bridge, which limits the size of marine-based equipment that can access the project work area from the water. During the TCRA, a single off-site location was identified that could accommodate the armor rock stockpiling and barge loading, and that was available for lease during the TCRA construction. The rock was stockpiled for barge loading over an approximate 1-acre footprint at the off-site staging area located upstream from the Site and along the San Jacinto River. This same location might not necessarily be available during the remedial construction phase.

5.1.3.7 Cost

The estimated present worth cost associated with this remedial alternative is $12.5 million (Appendix C). The capital costs for this remedial alternative are primarily associated with the construction of the Permanent Cap, including development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for Alternative 2N. The long-term costs are for monitoring and maintenance of the Permanent Cap, collecting and analyzing environmental samples, evaluating the data, and preparing reports to document MNR. The cost estimate for this alternative also includes Permanent Cap monitoring and maintenance and USEPA 5-year reviews as described in Appendix C, and also assumes available access to the TCRA Site by water from a location along the river and by land through the TxDOT ROW. The number of monitoring events is subject to approval by USEPA and may be changed.

5.1.4 Alternative 4N – Partial Solidification/Stabilization, Permanent Cap, Institutional Controls and Monitored Natural Recovery

5.1.4.1 Overall Protection of Human Health and the Environment

This remedial alternative would achieve the RAOs through a combination of treatment, enhanced engineering controls, ICs and MNR. S/S would be used to immobilize soil/sediment in the TCRA Site with the most highly contaminated material. A dioxin/furan value that exceeds 13,000 ng/kg $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter was used to define the most highly contaminated material. S/S may add another level of protection to the Armored Cap. A Permanent Cap as described under Alternative 3N would be constructed following the S/S process.

Affected sediment near the Upland Sand Separation Area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PRG, would be further isolated by deposition of additional sediment as described in Section 2.5 and Appendix A. Ongoing deposition may result in declines in surface sediment concentrations, however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion similar to that which was documented during the 1994 flood, then the predicted deposition may not occur. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. Monitoring of sediment conditions in this area would be performed to confirm that deposition of clean sediment was continuing to maintain $TEQ_{DF,M}$ concentrations in surface sediments to below the PRG for hypothetical recreational visitors.

The MNR plan would include methods for assessing whether deposition or erosion were occurring at monitoring stations between monitoring events. The actual scope and timeline of monitoring would be determined in coordination with USEPA during remedial design.

ICs would be used to:

- Alert property owners of the presence of subsurface materials exceeding PRGs
- Describe the need for protective equipment and training if excavation of subsurface materials exceeding PRGs is required in the Permanent Cap
- Describe requirements for the management of any excavated soil or sediment exceeding PRGs
- Describe the need to restore the cap or clean cover soil in these areas following any disturbance
- Establish limitations on dredging and anchoring within the footprint of the Permanent Cap as described for Alternatives 2N and 3N.

This remedy, like Alternatives 1N through 3N, would achieve protection of human health and the environment in the TCRA Site upon implementation. As with the previous alternatives, additional clean sediment may continue to be deposited within the area of the USEPA's Preliminary Site Perimeter through ongoing natural recovery processes. $TEQ_{DF,M}$ concentrations in the surface sediments may decline, and the buried sediment near the Upland Sand Separation Area with $TEQ_{DF,M}$ concentrations exceeding the PRG may be further isolated from potential receptors. While ongoing deposition may result in declines in surface sediment concentrations, however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion similar to that which was documented during the 1994 flood, then the predicted deposition may not occur.

5.1.4.2 Compliance with ARARs

Implementation of Alternative 4N would trigger additional compliance requirements beyond those discussed in Section 5.1.3 due to the removal and replacement of the existing Armored Cap, as well as the implementation of the S/S treatment. The removal and replacement of cap material would trigger compliance with CWA Section 404(b)(1) and other ARARs related to surface water quality standards. The S/S may result in a 20 percent increase in the volume of the sediment in the area of treatment because of bulking due to the addition of the stabilization amendment. Application of the S/S to approximately 52,000 cy of sediment is estimated to result in 60,000 to 65,000 cy of amended sediment. This increase in volume could trigger a need to review potential flood storage impacts with Federal Emergency Management Agency (FEMA) and Harris County. Based on preliminary hydrodynamic modeling, the long- term change to the maximum water surface elevation following stabilization under this alternative is estimated to be 0.01 feet, which is an indication that the effect of S/S is negligible and cannot be quantified within the predictive capability of the flood model.

It is anticipated that Alternative 4N, through implementation of the BMPs and the agency coordination actions outlined in Section 3.4, would generally meet the substantive requirements of the remainder of the ARARs in Table 3-1.

5.1.4.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative is primarily derived from the construction of the Permanent Cap and treating approximately 52,000 cy of sediment by S/S, combined with the natural recovery processes described previously. Flattening the slopes, where appropriate, as shown in Figures 4-3 and 4-4, would further increase the stability and long-term reliability of the containment as described in Section 5.1.3, and the protective perimeter barrier would provide additional long-term effectiveness. The stabilization of sediment with the highest $TEQ_{DF,M}$ concentrations exceeding 13,000 ng/kg would enhance the shear strength of the stabilized sediments. This alternative is also effective over the long-term because of declines in sediment surface concentrations due to natural recovery (Appendix A) throughout USEPA's Preliminary Site Perimeter. Ongoing deposition may result in declines in surface sediment concentrations, however, deposition rates are low in most areas, particularly shallow areas. Further, should the river geometry change as a result of extreme erosion similar to that which was documented during the 1994 flood, then the predicted deposition may not occur. As described in Section 5.1.2, ICs would protect the integrity of the Permanent Cap. Monitoring would confirm the continued deposition of clean sediment isolating the affected sediment outside of the footprint of the Permanent Cap. Because the waste material will remain in place in the San Jacinto River for this alternative, the potential exists that a release of waste material could occur as a result of a future extreme storm or hurricane, or the impact of a barge strike that may breach the cap during the hundreds of years that the dioxin/furan will remain hazardous.

A long-term fate and transport model simulation was conducted for Alternative 4N to evaluate the long-term effectiveness of this alternative and quantify potential water and sediment quality impacts as a result of releases during stabilization (see Section 4.2 of Appendix A). Results from this simulation indicate that surface sediment concentrations of TCDD averaged over the area within USEPA's Preliminary Site Perimeter increase by an estimated 15 percent for the 21-year duration of the simulation period compared to natural recovery scenarios; these predicted increases are a result of releases of sediment and dissolved phase dioxins and furans during stabilization, even with the use of BMPs and a post-dredge backfill and cap. However, the simulations did not consider the impact of a dioxin release that may result for a future extreme storm or hurricane, nor the impacts of a barge strike that may breach the cap. Over the long-term, ongoing deposition may also act to reduce concentrations in sediments impacted by dredge residuals and releases within the USEPA's Preliminary Site Perimeter, however, deposition rates are low in most areas, particularly shallow areas.

5.1.4.4 Reduction of Toxicity, Mobility or Volume

This remedial alternative includes the use of S/S treatment to reduce the potential mobility of soil/sediment exceeding PRGs. Approximately 52,000 cy of soil/sediment in the TCRA Site would be treated in situ. Remedies that incorporate treatment address a key goal set by USEPA for cleanup projects, as documented in 40 CFR 300.430 (e)(9)(D), "The degree to which alternatives employ recycling or treatment that reduces toxicity, mobility or volume shall be assessed, including how treatment is used to address the principal threats posed by the site" and 40 CFR 300.430 (f)(1)(E), "Each remedial action shall utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable."

5.1.4.5 Short-Term Effectiveness

Potential resuspension and releases, as discussed in Section 4.1, present short-term risks for this alternative because mixing the stabilization reagent requires disturbing the sediment, and engineered barrier controls are subject to leakage. The modeling presented in Appendix A demonstrates short-term water column impacts associated with Alternative 4N. Specifically, over the TCRA Site footprint, this alternative is estimated to increase the annual average water column concentration of TCDD by a factor of 10 in year 1 compared to existing conditions.

Treatment of the soil/sediment within the TCRA Site would require first removing the existing Armored Cap armor rock, geotextile and geomembrane in the affected area. This would increase the potential risk of a release during construction of the most impacted in situ soil/sediment at the TCRA Site. To evaluate the risk of removing the Armored Cap, a 3-year storm event was considered, which has an average predicted water surface elevation of 3.5 feet NAVD88 and would inundate portions of the work area, including the sheetpile enclosure shown in Figure 4-3. For the Alternative 4N construction duration of 17 months, there is an approximate 38 percent likelihood that this water surface elevation would be reached or exceeded (Appendix B). Such an event could result in resuspension and upstream/downstream transport of the TCRA sediments from the inundated portion of the construction footprint where the Armored Cap is removed. The removal of cap materials also increases the risk of releasing sediment adhering to those cap materials. These two mechanisms result in an increase in the short-term risk of recontamination beyond the limits of the work area.

Shallow mixing augers may be used to implement S/S with minimal exposure of workers to the impacted soil/sediment; however, isolating the soil/sediment with a sheetpile barrier has been included as a component of this alternative to manage the risk of exposure mentioned above, and to facilitate effective solidification in relatively dry conditions. In situ solidification of wet soil/sediments below surface water has not been widely demonstrated at full scale, and the presence of free water has been shown to inhibit the chemical reactions necessary to achieve effective S/S (e.g., Manitowoc River, Renholds 1998; Kita and Kubo 1983). The use of a sheetpile barrier does little to enhance the short-term effectiveness of this alternative because of documented effectiveness issues with engineered barriers discussed in Section 4.1, including
:

- Incomplete isolation due to gaps in sheetpiles that may occur during installation

- The need to provide openings in the sheetpile to balance water pressures on both sides of the pile. Placement of the sheetpiles in existing or constructed berms will strengthen the sheetpile walls and reduce the impact of this.

- The potential for river-current-induced scour adjacent to the sheetpile. Armoring of the external side of the berms and sheetpile walls will reduce the impact of this.

However, the three bullets listed above do not provide significant issues in shallow wall installations, such as a wall built at the crest of the outside face of the Western Cell berm, which is normally above the waterline. Gaps between sheet piles could be readily sealed, and there would not be a need to balance water pressures on both sides of the wall. Additionally, the base of the wall is already armored, which would limit the scour potential.

In addition to these documented issues with sheetpile barriers, the use of sheetpiles increases the risk of recontamination and resuspension of soil/sediments during sheetpile installation and removal (Ecology 1995), and potential cross-contamination associated with driving sheetpiling through impacted materials into non-impacted material. However, the area and mass of contamination impacted by the sheet piles leading to potential recontamination and resuspension of contaminated sediment during installation and removal are a small fraction of the reduction in potential releases achieved by their use over that of other BMPs such as silt curtains. Further, cross-contamination associated with driving sheet piling through impacted materials into non-impacted material does not pose additional risk because there would not be any exposure to the underlying materials, besides being of limited mass.

In addition to these environmental risks, construction for this alternative is estimated to require 1,600 truck trips (Table 4-4). This alternative would have higher greenhouse gas, PM, and ozone impacts associated with construction emissions from equipment (Table 4-4) as compared to the previous alternatives. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. From a worker safety perspective, there is also a moderate risk of accidental injury (Table 4-5) to workers during construction.

5.1.4.6 Implementability

The implementation of this remedial alternative, particularly the treatment of soil/sediment after removal of the Armored Cap, would be more challenging than implementation of Alternative 3N. Stabilization of soil/sediment in the floodplain and subtidal areas will require precautions, such as the use of a sheetpile barrier wall to minimize potential releases of materials once the Armored Cap is removed. Even with those precautions, because of the disturbance of sediments caused by removing the Armored Cap, and the additional handling of previously undisturbed sediments during the S/S process, the release of some of these impacted materials into the river or onto the surface of the undisturbed parts of the Armored Cap may be unavoidable, particularly if a storm or high water levels were to occur during construction. The results from chemical fate model simulations of Alternative 4N presented in Appendix A indicate that short-term increases in surface water concentrations could occur during the construction.

In addition, stabilization in areas that are normally below surface water increases the difficulty in successful implementation of this alternative. Construction of the Permanent Cap following S/S would be implementable with challenges as generally noted under Alternative 3N for armor rock placement. Monitoring would involve collecting and analyzing sediment samples and evaluating the data, which are routine procedures for qualified environmental consultants and laboratories. Establishing ICs is routine, so there are no significant administrative implementability issues associated with this remedial alternative. As with Alternative 3N, technical implementability issues include obtaining access to the project work area, limited availability of off-site locations for staging, material management, and barge access, and the low clearance under the I-10 bridge, which limits the size of marine-based equipment that can access the project work area from the water. As described under Alternative 3N, a 1-acre footprint was required for the off-site staging area to manage the rock stockpile. Because this alternative also requires treatment reagents, additional space could be necessary for the off-site staging area. This location used for the off-site staging area during TCRA construction might not necessarily be large enough to accommodate the work, or might not be available during the remedial construction phase.

5.1.4.7 Cost

The estimated present worth cost associated with this remedial alternative is $23.2 million (Appendix C). The capital costs for this remedial alternative are primarily associated with the S/S process and construction of the Permanent Cap, including development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for remedial Alternative 2N. The long-term costs are for monitoring the condition of the Permanent Cap, collecting and analyzing environmental samples, evaluating the data, preparing reports to document MNR, and monitoring and maintenance of the Permanent Cap. The estimated cost of this alternative includes USEPA 5-year reviews and also assumes available access to the TCRA Site by water from a location along the river and by land through the TxDOT ROW. The assumed number of monitoring events is discussed in Appendix C; the actual number of monitoring events is subject to approval by USEPA.

5.1.5 Alternative 5N – Partial Removal, Permanent Cap, Institutional Controls and Monitored Natural Recovery

5.1.5.1 Overall Protection of Human Health and the Environment

This remedial alternative achieves the RAOs through a combination of soil/sediment removal, enhanced engineering controls, MNR and ICs. Following removal of portions of the existing Armored Cap, soil and sediment with $TEQ_{DF,M}$ concentrations greater than the USEPA-identified limit of 13,000 ng/kg $TEQ_{DF,M}$ would be removed, dewatered, and transported off-site for disposal. The dredge area would be backfilled and a Permanent Cap as described in Alternative 3N would be constructed following removal of the soil/sediment.

Affected sediment near the Upland Sand Separation Area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PRG, would be further isolated by deposition of additional sediment as described in Section 2.6 and Appendix A. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. Monitoring of sediment conditions in this area would be performed to confirm that deposition of clean sediment was continuing to maintain $TEQ_{DF,M}$ concentrations in surface sediments below the PRG for protection of hypothetical recreational visitors. The MNR plan would include methods for assessing whether deposition or erosion was occurring. Appendix C describes cost assumptions used in this FS Report for MNR monitoring. The actual scope and timeline of monitoring would be determined in coordination with USEPA during remedial design.

ICs would be used to:

- Alert property owners of the presence of remaining subsurface material exceeding PRGs

- Describe the need for protective equipment and training to limit exposure to contaminants if future additional excavation is required in the footprint of the Permanent Cap

- Describe requirements for the management of any excavated soil or sediment

- Describe the need to restore the cap or clean cover soil in these areas following any disturbance

- Establish limitations on dredging and anchoring within the footprint of the Permanent Cap as described in Alternatives 2N to 4N.

5.1.5.2 Compliance with ARARs

Implementation of Alternative 5N would include the removal of portions of the existing Armored Cap, removal of underlying soil/sediment, and transportation of sediment to an upland disposal facility. The removal of the Armored Cap and placement of rock for Permanent Cap construction would trigger compliance with CWA Section 404(b)(1) and along with the dredging action would trigger other ARARs related to surface water quality standards. Should Alternative 5N be identified as the remedy, additional evaluations would be conducted to determine the potential habitat impacts related to the construction of the Permanent Cap, dredging, and backfill.

The removal of sediment would require the construction of an off-site material handling facility near the work area to offload barges, manage waste, stockpile and dewater sediment, and load these materials onto trucks or rail cars for off-site disposal. The construction and operation of the material handling facility will require substantial compliance with relevant permit requirements. Although land for the material handling facility may not be available within the USEPA's Preliminary Site Perimeter, the NCP (40 CFR 300.430(e)) defines on-site for this purpose as "the areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response action."

Construction of the Permanent Cap would require the placement of approximately 3,400 cy of additional cap armor rock material. Hydrodynamic modeling was performed to confirm that the placement of the additional armor rock would not significantly affect flood-storage capacity in the San Jacinto River (Appendix B). Based on the results of this modeling, the long-term change to the maximum water surface elevation following placement of the additional armor rock under this alternative is estimated to be -0.01 to -0.02 feet, which is an indication that the effect of rock placement is negligible and immeasurable within the predictive capability of the flood model.

Alternative 5N would be expected, through implementation of the BMPs and the agency coordination actions outlined in Section 3.4, to generally meet the substantive requirements of the ARARs in Table 3-1.

5.1.5.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative is primarily derived from the construction of the Permanent Cap and removing a substantial percentage of the highest concentration material (approximately 52,000 cy) from the Site, combined with natural recovery as described previously. Long-term effectiveness is reduced by the fact that this alternative will likely generate dredge residuals from the resuspension of dioxin-impacted sediments that have been documented on other projects as discussed in the RAM (Anchor QEA 2012b) and in Section 4. These dredge residuals would likely have concentrations that are similar to the concentrations of the materials that are dredged (e.g., greater than 13,000 ng/kg $TEQ_{DF,M}$). Because the waste material will remain in place in the San Jacinto River for this alternative, the potential exists that a release of waste material could occur as a result of a future extreme storm or hurricane, or the impact of a barge strike that may breach the cap during the hundreds of years that the dioxin/furan will remain hazardous.

A long-term fate and transport model simulation was conducted for Alternative 5N to evaluate the comparative long-term effectiveness of this alternative and quantify potential water and sediment quality impacts during dredging (see Section 4.2 of Appendix A). Results from this simulation indicate that surface sediment concentrations of TCDD averaged over the area within USEPA's Preliminary Site Perimeter increase by nearly 25 percent for the

21-year duration of the simulation period compared to natural recovery scenarios; these predicted increases are a result of releases of sediment and dissolved phase dioxins and furans during dredging, even with the use of engineering controls and a post-dredge backfill and cap. However, the actual levels would be reduced by the use of BMPs during construction. Further, the simulation did not consider the impact of a dioxin release that may result for a future extreme storm or hurricane, nor the impacts of a barge strike, that may breach the cap. Ongoing deposition from natural recovery processes would also act to reduce concentrations impacted by dredge residuals and releases within the USEPA's Preliminary Site Perimeter over the long-term, however, deposition rates are low in most areas, particularly shallow areas.

The removal of sediment with $TEQ_{DF,M}$ concentrations exceeding 13,000 ng/kg eliminates a potential future source of high concentration sediments from the TCRA Site. Flattening the slopes, where appropriate, as shown in Figures 4-3 and 4-4, and the other work to be performed in constructing the Permanent Cap, would further increase the stability and long-term reliability of the containment as described in Section 5.1.3. This alternative is also effective over the long-term because of declines in sediment surface concentrations due to natural recovery (Appendix A) throughout USEPA's Preliminary Site Perimeter. As described in Section 5.1.2, ICs would protect the integrity of the Permanent Cap and the layer of clean surface soil. Monitoring would confirm the continued deposition of clean sediment isolating the affected sediment outside of the footprint of the Permanent Cap.

5.1.5.4 Reduction of Toxicity, Mobility or Volume

This remedial alternative would reduce the volume of material exceeding PRGs within the USEPA's Preliminary Site Perimeter. Approximately 52,000 cy of sediment in the TCRA Site would be removed for disposal. Sediment dewatering by amendment prior to transporting for disposal may reduce the potential mobility of contaminants during transportation and at the disposal facility.

5.1.5.5 Short-Term Effectiveness

Potential resuspension and releases, as discussed in Section 4.1.1, present short-term risks for this alternative because of the dredging, and engineered barrier controls are subject to leakage. The modeling presented in Appendix A demonstrates short-term water column impacts associated with Alternative 5N. Specifically, over the TCRA Site footprint, this alternative is estimated to increase the annual average water column concentration of TCDD by a factor of about 50 in year 1 compared to existing conditions. However, the actual levels would be reduced by the use of BMPs during construction, including de-watering and excavation in the dry.

Removal of sediment under this alternative would require first removing the existing Armored Cap armor rock, geotextile and geomembrane in the affected area. This would increase the potential risk of a release during removal of soil/sediment with concentrations exceeding 13,000 $TEQ_{DF,M}$. To evaluate the risk of removing the Armored Cap, a 3-year storm was considered, which has an average predicted water surface elevation of 3.5 feet NAVD88 and would inundate portions of the work area, including the sheetpile enclosure shown in Figure 4-3. For the Alternative 5N construction duration of 13 months, there is an approximate 30 percent likelihood this water surface elevation would be reached or exceeded (Appendix B). Such an event could result in resuspension and upstream/downstream transport of sediments from the inundated portion of the construction footprint where the cap is removed.

In addition to a storm event as described above, releases would also be expected during dredging with potential sediments impacted by releases of dioxins and furans potentially settling onto areas within the USEPA's Preliminary Site Perimeter, and potentially causing temporary increases in surface water and tissue concentrations for various COCs. For example, results from chemical fate model simulations presented in Appendix A indicate that short-term increases in surface water concentrations could occur, with such increases being significant at localized scales during the construction (e.g., an order of magnitude). However, the actual levels would be reduced by the use of BMPs during construction, including de-watering and excavation in the dry. Even with those precautions, it would be difficult to avoid releasing some of these materials exceeding PRGs into the river or onto the surface of the undisturbed parts of the Permanent Cap. That risk would be increased if a storm or high water levels were to occur during construction, as described previously.

Additional environmental risks include the possibility of spills during transportation to the disposal facility and possible releases from the off-site landfill itself. In addition to these environmental risks, as compared to the previous four alternatives, construction for this alternative is estimated to require 9,300 truck trips (Table 4-4). This alternative would have higher greenhouse gas and PM. impacts and ozone generating emissions associated with construction emissions from equipment operating within the project work area, as well as from equipment required for transportation and disposal of excavated sediments (Table 4-4). However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. From a worker safety perspective, there is a low to moderate risk of accidental injury to workers during construction (Table 4-5). The remedy would achieve full protection in the TCRA Site upon completion of construction. Additional clean sediment continues to be deposited throughout the USEPA's Preliminary Site Perimeter, $TEQ_{DF,M}$ concentrations in surface sediments would continue to decline and the buried sediment near the Upland Sand Separation Area with $TEQ_{DF,M}$ concentrations exceeding the PRG would be further isolated from potential receptors.

5.1.5.6 Implementability

There are several implementability concerns associated with this remedial alternative. As discussed above, removal of sediment in the floodplain would require the use of engineering controls to minimize any releases of impacted sediment during construction and some releases to the surrounding environment could occur as described in Section 4.1. The modeling of Alternative 5N presented in Appendix A shows that these releases could impact surface water and surface sediment concentrations on both short and long time scales.

Further, on-site space is very limited to accommodate contractor access, staging, stockpiling materials, and managing excavated sediment for transportation to an off-site disposal site. An off-site facility would need to be identified and secured to manage dredged materials (including dewatering, transloading, and shipping) and to stockpile and load imported armor rock. Given the nature of the material being managed at the off-site facility, locating a suitable property and willing landowner could be a challenge. During the TCRA, a single off-site location was identified that could accommodate the armor rock stockpiling and barge loading, and that was available for lease during the TCRA construction. The rock was stockpiled for barge loading over an approximate 1-acre footprint at the off-site staging area located upstream from the site and along the San Jacinto River. This same location might not necessarily be compatible with managing dredged sediment, which can require a relatively large footprint for processing, and/or might not be available during the remedial construction phase. For example, the Port Gamble Interim Action dredging, which required excavation of 16,500 cy of material, required a dredge material stockpile footprint of approximately 3 acres in size (Hart Crowser 2007).

Replacement of the cap following sediment removal and backfilling would be implementable as noted for Alternative 3N. Monitoring would involve collecting and analyzing sediment samples and evaluating the data, which are routine procedures for qualified environmental consultants and laboratories. Establishing ICs is routinely done, so there are not anticipated to be administrative implementability issues associated with this remedial alternative either.

5.1.5.7 Cost

The estimated present worth cost associated with this remedial alternative is $38.1 million (Appendix C). The capital costs for this remedial alternative are primarily associated with the sediment removal and disposal and construction of the Permanent Cap, including development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for Alternative 2N. The long-term costs are for monitoring the condition of the Permanent Cap, collecting and analyzing environmental samples, evaluating the data, preparing reports to document the MNR, maintenance of the Permanent Cap, and USEPA 5-year reviews. Assumptions regarding monitoring and maintenance are described in Appendix C. The actual monitoring requirements and number of monitoring events will be subject to approval by USEPA and would be determined during remedial design. The estimated cost of this alternative assumes available access to the TCRA Site by water from a location along the river and by land through the TxDOT ROW.

5.1.6 Alternative 5aN – Partial Removal of Materials Exceeding the PRG, Permanent Cap, Institutional Controls and Monitored Natural Recovery

5.1.6.1 Overall Protection of Human Health and the Environment

This remedial alternative would achieve the RAOs through a combination of soil/sediment removal, capping, ICs and MNR. Soil/sediment in the TCRA Site where the water depth is 10 feet or less and with $TEQ_{DF,M}$ concentrations exceeding the hypothetical recreational visitor PRG (200 ng/kg), plus soils that exceed 13,000 ng/kg $TEQ_{DF,M}$ in any water depth, would be removed, dewatered, and transported to a permitted landfill for disposal.

This alternative would require partial removal of the Armored Cap. Soil/sediment removal would be performed behind an engineered barrier, including a berm in shallow water areas of the project work site, and a sheetpile in deeper water areas of the project work site. Following removal of the soil/sediment, a two layer residuals cover would be placed.

A Permanent Cap as described under Alternative 3N would be constructed in the area of the TCRA Site where the PRG is exceeded but the water is deeper than 10-feet.

Affected sediment near the Upland Sand Separation Area, which is already isolated from potential receptors by several feet of sediment with $TEQ_{DF,M}$ concentrations below the PRG, would be further isolated by deposition of additional sediment as described in Section 2.6

and Appendix A. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. Monitoring of sediment conditions in this area would be performed to confirm that deposition of clean sediment was continuing to maintain $TEQ_{DF,M}$ concentrations in surface sediments below the PRG for protection of hypothetical recreational visitors. The MNR plan would include methods for assessing whether deposition and erosion were occurring. MNR monitoring assumptions are described in more detail in Appendix C. The actual scope and timeline of monitoring would be determined in coordination with USEPA during remedial design.

ICs would be used to:

- Alert property owners of the presence of remaining subsurface material exceeding PRGs
- Describe requirements for the management of any excavated soil or sediment
- Describe the need to restore the Permanent Cap or clean cover soil in these areas following any disturbance
- Establish limitations on dredging and anchoring within the footprint of the Permanent Cap as described in Alternatives 2N to 5N.

5.1.6.2 Compliance with ARARs

Alternative 5aN would generally trigger the same compliance requirements as Alternative 5N. If Alternative 5aN is identified as the preferred alternative, additional evaluations would need to be conducted to determine the potential habitat impacts related to impacts of dredging and placement of clean residual layer management materials to document compliance with CWA Section 404(b)(1) and other natural resource based ARARs.

Removal of sediments and placement of a residuals cover would result in a net lowering of the mudline in the work area. Hydrodynamic modeling was performed to evaluate the effect of this change on flood-storage capacity in the San Jacinto River (Appendix B). Based on the results of this modeling, the long-term change to the maximum water surface elevation following dredging and residuals management placement is estimated to be -0.04 to -0.05 feet, which may not be measurable using the predictive capability of the flood model.

5.1.6.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative is primarily derived from the removal of soil and sediment and the enhancement of the existing Armored Cap. Approximately 137,600 cy of soil and sediment would be removed from beneath the existing Armored Cap. The anticipated limits of the excavation are shown in Figures 4-5 and 4-6. The dredging activity would result in a reduction in the volume of soil/sediment with concentrations above 200 mg/kg $TEQ_{DF,M}$; however, it is expected that a residual layer of impacted material with $TEQ_{DF,M}$ above 200 mg/kg would remain at the bottom of the excavated surfaces due to dredging-related releases as described in Section 4.1. The concentration of those residual materials would be similar to the removed materials and would likely require a clean sediment residuals cover across the dredge footprint. Because the waste material will remain in place in the San Jacinto River for this alternative, the potential exists that a release of waste material could occur as a result of a future extreme storm or hurricane, or the impact of a barge strike that may breach the cap during the hundreds of years that the dioxin/furan will remain hazardous.

A long-term fate and transport model simulation was conducted for Alternative 5aN to evaluate the comparative long-term effectiveness of this alternative and quantify potential water and sediment quality impacts during dredging (see Section 4.2 of Appendix A). Results from this simulation indicate that surface sediment concentrations of TCDD averaged over the USEPA's Preliminary Site Perimeter increase by approximately two- to three-fold for the 21-year duration of the simulation period compared to natural recovery scenarios; these predicted increases are a result of releases of sediment and dissolved phase dioxins and furans during dredging and from sediment residuals within the TCRA Site. However, the actual levels would be reduced by the use of BMPs during construction, including de-watering and excavation in the dry. However, the simulation did not consider the impact of a dioxin release that may result for a future extreme storm or hurricane, nor the impacts of a barge strike, that may breach the cap. Over the long-term, ongoing deposition would also act to reduce concentrations associated with dredge residuals and releases within the USEPA's Preliminary Site Perimeter, however, deposition rates are low in most areas, particularly shallow areas.

5.1.6.4 Reduction of Toxicity, Mobility or Volume

This remedial alternative would remove sediment exceeding PRGs from within the USEPA's Preliminary Site Perimeter. Approximately 137,600 cy of sediment would be removed from within the USEPA's Preliminary Site Perimeter for disposal. Sediment dewatering by amendment prior to transporting the sediment to a landfill for disposal would reduce the potential mobility of constituents during transportation and at the disposal facility. Water generated from sediment dewatering would need to be treated on-site for discharge, or collected and transported off-site for disposal.

5.1.6.5 Short-Term Effectiveness

Potential resuspension and releases, as discussed in Section 4.1.1, present short-term risks for this alternative. The engineered barrier controls are subject to leakage and may occur during construction even with the use of BMPs. The modeling presented in Appendix A demonstrates short-term water column impacts associated with Alternative 5aN. Specifically, over the TCRA Site footprint, this alternative is estimated to increase the annual average water column concentration of TCDD by a model derived factor of about 90 in year 1 compared to existing conditions. However, the actual levels would be reduced by the use of BMPs during construction, including de-watering and excavation in the dry.

Removal of sediment from the TCRA Site would require first removing the existing Armored Cap in the affected area. This would increase the potential risk of a release during construction of sediments containing the highest concentrations of dioxins and furans detected within USEPA's Preliminary Site Perimeter if a storm or flood event were to compromise the perimeter barrier, when sediments that are currently capped would be exposed. To evaluate the risk of removing the Armored Cap, a 3-year storm was considered, which has an average predicted water surface elevation of 3.5 feet NAVD88 and would inundate portions of the work area, including overtopping the perimeter berm and the sheetpile enclosure. For the Alternative 5aN construction duration of 19 months, there is an approximate 40 percent likelihood that this water surface elevation would be reached or exceeded (Appendix B). Such an event could result in resuspension and upstream/downstream transport of the TCRA sediments from the inundated portion of the construction footprint where the cap is removed.

In addition, short-term water quality impacts would occur due to dredging operation releases (Appendix A). For example, the model simulation of Alternative 5aN indicates that for an assumed dredge release rate of 0.85 percent[4] (based on experience from other dredging projects with different BMPs, where an engineered barrier was used; see Table 4-2), average surface water 2,3,7,8-TCDD concentrations within the USEPA's Preliminary Site Perimeter would be predicted to increase by more than an estimated order of magnitude during dredging. However, the actual levels would be reduced by the use of BMPs during construction. These releases would also be expected to increase tissue concentrations in the early years following remedy implementation and also result in slight increases in surface sediment concentration in surrounding areas (Appendix A).

[4] As discussed in Appendix A, this percentage applies to the constituent mass within the dredge prism, and is simulated as a dissolved phase release in the model.

In addition to these environmental risks, construction for this alternative is estimated to require 12,855 truck trips (Table 4-4). Relative to the other alternatives, this alternative would have high greenhouse gas, PM, and ozone impacts associated with construction emissions from equipment operating in the work areas (Table 4-4), as well as from equipment required for off-site transportation and disposal of excavated sediments. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. From a worker safety perspective, there is a moderate to high risk of accidental injury to workers during construction (Table 4-5). The remedy would be intended to achieve full protection upon completion of construction; however, there could be releases of dioxins and furans to the surrounding environment during implementation that would be unavoidable and would affect the water column, increase sediment concentrations beyond the work area, and increase tissue concentrations of COCs.

5.1.6.6 Implementability

There are implementability concerns associated with this remedial alternative. Water conditions are generally shallow in most of the work area, precluding the use of larger marine-based equipment that requires deeper-draft barges. Thus, the size of the pile driving equipment would be limited to smaller cranes with less capability to handle dense driving conditions. Even with the use of a sheetpile barrier some loss is expected based on documented case histories (see Section 4).

Further, on-site space is limited to accommodate access, staging and stockpiling materials and excavated sediment for transportation to an off-site disposal site. The considerations discussed under Alternative 5N for locating and securing an off-site material handling area are also applicable to this alternative. Given the scope and scale of this alternative, it is likely that a relatively large river-side property near the work area would need to be leased for the duration of the work to accommodate staging, material processing, stockpiling, and transloading of materials. The logistical concerns over locating and securing a suitable off-site material handling area would be more for this remedial alternative than for the partial removal (Alternative 5N) because of the longer duration of the project (19 months versus 13 months) and the greater extent of the removal area, which would leave less on-site upland space for managing materials, as well as the greater volume of material removed which could require a larger off-site location. There may be greater community impacts (traffic, noise, air emissions, etc.) during implementation. Finally, the volume of material removed could have an impact on the capacity of available landfills; thus the acceptance of this amount of material for disposal is uncertain. Establishing ICs is routinely done, so there are not any anticipated administrative implementability issues associated with this remedial alternative.

5.1.6.7 Cost

The estimated present worth cost associated with this remedial alternative is $77.9 million. The capital costs for this remedial alternative are primarily associated with the sediment removal and disposal and construction of the Permanent Cap, including development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

The long-term costs are for monitoring the condition of the Permanent Cap, collecting and analyzing environmental samples, evaluating the data, preparing reports to document the MNR, maintenance of the Permanent Cap, and USEPA 5-year reviews. Cost assumptions regarding monitoring and maintenance are described in Appendix C. The actual monitoring requirements and number of monitoring events will be subject to approval by USEPA and would be determined during remedial design. Further details on the cost assumptions for this alternative are presented in Appendix C.

5.1.7 Alternative 6N – Full Removal of Materials Exceeding the PRG, Institutional Controls and Monitored Natural Recovery

5.1.7.1 Overall Protection of Human Health and the Environment

This remedial alternative would achieve the RAOs through a combination of soil/sediment removal, MNR and ICs (for the residuals following removal). Soil/sediment in the TCRA Site and near the Upland Sand Separation Area with $TEQ_{DF,M}$ concentrations exceeding the hypothetical recreational visitor PRG (200 ng/kg) would be removed, dewatered, and transported to a permitted landfill for disposal. As for Alternatives 5N and 5aN, complete removal of materials exceeding the PRG may not be possible because of dredging residuals, which will leave a layer material exceeding PRGs that will need to be managed by placing a post-dredge clean cover. Monitoring may involve collecting and analyzing sediment, tissue, surface water, and ground water samples and evaluating the data. ICs would be used to:

- Alert property owners of the presence of remaining subsurface material exceeding PRGs, if necessary.

5.1.7.2 Compliance with ARARs

Implementation of Alternative 6N would generally trigger the same compliance requirements as Alternatives 5N and 5aN. If Alternative 6N is identified as the preferred alternative, additional evaluations would need to be conducted to determine the potential habitat impacts related to impacts of dredging and placement of clean residual layer management materials to document compliance with CWA Section 404(b)(1) and other natural-resource based ARARs. Removal of sediments and placement of a residuals cover would result in a net lowering of the mudline in the work area. Hydrodynamic modeling was performed to evaluate the effect of this change on flood-storage capacity in the San Jacinto River (Appendix B). Based on the results of this modeling, the long-term change to the maximum water surface elevation following dredging and residuals management placement is estimated to be -0.04 to -0.05 feet, which may not be measurable within the predictive capability of the flood model.

5.1.7.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative is derived from the removal of soil and sediment exceeding the PRG. Approximately 200,100 cy of soil and sediment would be removed from the TCRA Site and from the area near the Upland Sand Separation Area. The anticipated limits of the excavation are shown in Figures 4-5 and 4-6. The dredging activity would reduce the volume of soil/sediment with concentrations above 200 mg/kg $TEQ_{DF,M}$; however, it is expected that a residual layer of contaminated materials would remain at the bottom of the excavated surfaces as explained relative to Alternative 5aN. The concentration of those residual materials would be similar to the removed materials and would likely require a clean sediment residuals cover across the dredge footprint.

A long-term fate and transport model simulation was conducted for Alternative 6N to evaluate the comparative long-term effectiveness of this alternative and quantify potential water and sediment quality impacts during dredging (see Section 4.2 of Appendix A). Results from this simulation indicate that surface sediment concentrations averaged over the USEPA's Preliminary Site Perimeter increase by an factor of 3 for the 21-year duration of the simulation period compared to natural recovery scenarios; these predicted increases are a result of releases of sediment and dissolved phase dioxins and furans during dredging and the presence of sediment residuals within the TCRA Site. However, the actual levels would be reduced by the use of BMPs during construction. However, the actual levels would be reduced by the use of BMPs during construction, including berms, sheet piles, dewatering, excavation in the dry, etc. Conversely, Alternative 6N would not result in the potential for a future release due to an extreme storm or hurricane, nor the impacts of a barge strike as is the case for all of the other alternatives because the waste material has been removed. Over the long-term, ongoing deposition would also act to reduce $TEQ_{DF,M}$ concentrations in sediment associated with dredge residuals and releases within the USEPA's Preliminary Site Perimeter but not achieving the same levels at the end of the simulation period as modeled for Alternatives 1N through 3N.

5.1.7.4 Reduction of Toxicity, Mobility or Volume

This remedial alternative would use S/S treatment (sediment dewatering by amendment) to reduce the mobility of COCs during transportation and at the disposal facility. Approximately 200,100 cy of sediment with $TEQ_{DF,M}$ concentrations exceeding PRGs would be removed from within the USEPA's Preliminary Site Perimeter for disposal. Water generated from sediment dewatering would need to be treated on-site for discharge, or collected and transported off-site for disposal.

5.1.7.5 Short-Term Effectiveness

Potential resuspension and releases, as discussed in Section 4.1.1, present short-term risks for this alternative. However, these short term risks would be mitigated by the use of BMPs and engineering controls to reduce resuspension. The modeling presented in Appendix A demonstrates short-term water column impacts associated with Alternative 6N. Specifically, over the TCRA Site footprint, this alternative is estimated to increase the annual average water column concentration of TCDD by a factor of more than 100 in year 1 compared to existing conditions. However, the actual levels would be reduced by the use of BMPs during construction, including dewatering and excavation in the dry.

Removal of sediment from the TCRA Site would require first removing the existing Armored Cap in the affected area. This would increase the potential risk of a release during removal of sediment with the highest $TEQ_{DF,M}$ concentrations within the USEPA's Preliminary Site Perimeter, particularly if a storm or flood event occurred, when the sediment that is currently capped would be exposed. To evaluate the risk of removing the Armored Cap, a 3-year storm was considered, which has an average predicted water surface elevation of 3.5 feet NAVD88 and would inundate portions of the work area. For the Alternative 6N construction duration of 16 months, there is an approximate 36 percent likelihood that this water surface elevation would be reached or exceeded (Appendix B). Such an event could result in resuspension and upstream/downstream transport of the TCRA sediments from the inundated portion of the construction footprint where the cap is removed.

In addition, short-term water quality impacts would occur due to dredging operation releases (Appendix A). For example, the model simulation of Alternative 6N indicates that for an assumed dredge release rate of 3 percent[5] (based on experience from other dredging projects; see Table 4-2), average surface water 2,3,7,8-TCDD concentrations within the USEPA's Preliminary Site Perimeter are estimated to increase by more than an order of magnitude during dredging. These releases would also be expected to increase tissue concentrations in the early years following remedy implementation and also result in increases in surface sediment concentration in surrounding areas (Appendix A). However, the actual levels would be reduced by the use of BMPs during construction, including dewatering and excavation in the dry.

In addition to these environmental risks, construction for this alternative is estimated to require 17,500 truck trips (Table 4-4). Relative to the other alternatives, this alternative would have higher greenhouse gas, PM, and ozone impacts associated with construction emissions from equipment operating in the work areas (Table 4-4), as well as from equipment required for off-site transportation and disposal of excavated sediments. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. From a worker safety perspective, there is a moderate to high risk of accidental injury to workers during construction (Table 4-5). The remedy would be intended to achieve full protection upon completion of construction; however, there may be releases of dioxins and furans to the surrounding environment during implementation that would be unavoidable and would affect the water column, increase sediment concentrations beyond the work area, and increase tissue concentrations of COCs in the short-term.

5.1.7.6 Implementability

There are several implementability concerns associated with this remedial alternative. As discussed above, removal of sediment in the floodplain would require the use of engineering controls to minimize the release of contaminated sediment during construction; nevertheless some loss is expected based on documented case histories and published guidance (e.g., USACE 2008) even with the use of those controls. It would be extremely difficult to avoid releasing impacted materials into the river, particularly if a storm or high water levels occur during construction.

Further, on-site space is limited to accommodate access, staging and stockpiling materials and excavated sediment for transportation to an off-site disposal site. The considerations discussed under Alternatives 5N and 5aN for locating and securing an off-site material handling area are also applicable to this alternative. However, the logistical concern over

---

[5] As discussed in Appendix A, this percentage applies to the chemical mass within the dredge prism, and is simulated as a dissolved phase release in the model.

locating and securing an off-site facility would be more significant for this remedial alternative than for Alternative 5N because of the longer duration of the project and the greater volume of material removed than that required for Alternatives 5N and 5aN, and which would have greater community impacts (traffic, noise, air emissions, etc.) during implementation. Given the scope and scale of this alternative, it is likely that a larger river-side property near the work area would need to be leased for the duration of the work to accommodate staging, material processing, stockpiling, and transloading of materials. The need for such an area adds additional complexity to this alternative. Finally, the volume of material removed could have an impact on the capacity of available landfills; thus the acceptance of this amount of material for disposal is less certain. Establishing ICs is routine, so there are no anticipated administrative implementability issues associated with this remedial alternative.

5.1.7.7 Cost

The estimated present worth cost associated with this remedial alternative is $99.2 million. The capital costs for this remedial alternative are primarily associated with the sediment removal and disposal, including development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

The long-term costs are for collecting and analyzing environmental samples, evaluating the data, preparing reports to document the MNR and USEPA 5-year reviews. The costs of preparing sampling plans, deed restrictions and notices, and a soil management plan are the same as those for remedial Alternative 2N. Cost assumptions regarding monitoring and maintenance for this alternative are described in Appendix C. The actual monitoring requirements and number of monitoring events will be subject to approval by USEPA and would be determined during remedial design. Further details on the cost assumptions for this alternative are presented in Appendix C.

5.2 Area South of I-10

5.2.1 Alternative 1S – No Further Action

5.2.1.1 Overall Protection of Human Health and the Environment

This remedial alternative would not be protective of human health and the environment. Although the subsurface soil is isolated from potential receptors by several feet of soil with

$TEQ_{DF,M}$ concentrations below the PRG for the hypothetical future construction worker, this exposure scenario considers excavation and potential exposure to subsurface soil to a depth of 10-feet below grade. Further, in the absence of controls, soil that is currently isolated from receptors by depth could potentially be excavated and placed on the surface.

5.2.1.2 Compliance with ARARs

Alternative 1S would not result in construction impacts or other changes to baseline conditions that would trigger any action-, chemical-, or location-specific ARARs identified in Table 3-1.

5.2.1.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative was evaluated considering the potential for natural forces or human activity to expose the sediment or soil with $TEQ_{DF,M}$ concentrations that exceed the applicable PRG. If no action is taken to alert future property owners or construction workers to the presence of subsurface soil with $TEQ_{DF,M}$ concentrations above the PRG, workers performing excavation in the specific areas shown in Figure 4-11 could be exposed to elevated $TEQ_{DF,M}$ concentrations.

5.2.1.4 Reduction of Toxicity, Mobility or Volume

There is no reduction of TMV due to treatment associated with this remedial alternative.

5.2.1.5 Short-Term Effectiveness

There are no short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative.

5.2.1.6 Implementability

There are no technical or administrative implementability issues associated with this remedial alternative.

5.2.1.7 Cost

The estimated present worth cost associated with this remedial alternative is $140,000 (Appendix C). The capital costs for this remedial alternative are associated with conducting USEPA 5-year reviews.

5.2.2 Alternative 2S – Institutional Controls

5.2.2.1 Overall Protection of Human Health and the Environment

This remedial alternative would achieve the RAOs through the implementation of ICs. The following ICs would be implemented:

- Deed restrictions would be applied in the area south of I-10 where the depth-weighted average $TEQ_{DF,M}$ concentrations in upper 10-feet of subsurface soil exceed the soil PRG for the hypothetical future construction worker.

- Notices would be attached to deeds of affected properties to alert potential future purchasers of the presence of waste and soil with $TEQ_{DF,M}$ concentrations exceeding the soil PRG.

Notifying future property owners and construction workers would eliminate the exposure pathway to impacted soil. Potential health risks to hypothetical future construction workers would be addressed by the implementation of this remedial alternative. The ICs would provide long-term protection against anthropogenic disturbance of the clean surface soil and the underlying impacted soil.

5.2.2.2 Compliance with ARARs

The implementation of ICs would not involve activities that would trigger ARARs. Therefore, no compliance issues are anticipated for this remedial alternative.

5.2.2.3 Long-Term Effectiveness

Soil in the area of investigation south of I-10 with the $TEQ_{DF,M}$ concentrations greater than the PRG is isolated from potential receptors by a layer of at least 2-feet of soil with $TEQ_{DF,M}$ concentrations well below the PRG for hypothetical construction workers. Long-term effectiveness is provided by the ICs, which would alert future construction workers to the presence and location of soil with elevated $TEQ_{DF,M}$ concentrations, identify the need for appropriate PPE, and identify restrictions on the placement of soil excavated from the affected areas.

5.2.2.4 Reduction of Toxicity, Mobility or Volume

There is no reduction of TMV due to treatment associated with this remedial alternative.

5.2.2.5 Short-Term Effectiveness

There are no short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative. The remedy would achieve full protection in the area south of I-10 immediately.

5.2.2.6 Implementability

There are no technical implementability issues associated with this remedial alternative. Establishing ICs is routine and the current property owners have generally been cooperative with activities required for the remedial investigation.

5.2.2.7 Cost

The estimated present worth cost associated with this remedial alternative is $270,000 (Appendix C). The capital costs for this remedial alternative are associated with preparation of deed restrictions and notices and a soil management plan, and conducting USEPA 5-year reviews.

5.2.3 Alternative 3S – Enhanced Institutional Controls

5.2.3.1 Overall Protection of Human Health and the Environment

This remedial alternative would achieve the RAOs through a combination of ICs and engineering controls. ICs would be the same as those described in Section 5.2.2. The engineering controls used to enhance the effectiveness of the ICs (subsurface marker layer and bollards) would alert to potential future construction workers of the presence of deeper soil with elevated $TEQ_{DF,M}$ concentrations.

5.2.3.2 Compliance with ARARs

This remedial alternative would involve limited excavation and stockpiling of shallow soil to place the marker layer and bollards. Construction activities would comply with ARARs, including the control of dust and stormwater.

5.2.3.3 Long-Term Effectiveness

This remedial alternative would control the potential risk to hypothetical future construction workers by providing warnings and information on how to control exposure to soil with $TEQ_{DF,M}$ concentrations exceeding the PRG. The marker layer and bollards would identify the limits of the impacted areas and alert potential future construction workers to the presence of impacted soil and the need to take the precautions associated with excavating the impacted soil.

5.2.3.4 Reduction of Toxicity, Mobility or Volume

There is no reduction of TMV due to treatment associated with this remedial alternative.

5.2.3.5 Short-Term Effectiveness

There are minimal short-term risks to the community, ecological receptors, or workers associated with the implementation of this remedial alternative. Impacted soil would not be disturbed by the shallow excavation or the bollard installation, and measures would be implemented to control dust, stormwater runoff, and tracking of soil on equipment leaving the site. The remedy would achieve full protection in the area south of I-10 immediately upon implementation.

5.2.3.6 Implementability

There are no technical implementability issues associated with this remedial alternative. Placement of the marker layer and bollards are standard construction items, requiring no specialized equipment. Other than safety training required for workers at all cleanup sites, there are no specialized requirements for workers. Establishing ICs is routine, but landowners may raise objections to the presence of the bollards to be installed in implementing this alternative, which may create obstacles to the implementability of this alternative.

5.2.3.7 Cost

The estimated present worth cost associated with this remedial alternative is $660,000 (Appendix C). The capital costs for this remedial alternative are associated with excavation and replacement of soil, placement of the marker layer, installation of bollards, and the preparation of deed restrictions, notices, and a soil management plan, and conducting USEPA 5-year reviews.

5.2.4 Alternative 4S – Removal and Off-site Disposal

5.2.4.1 Overall Protection of Human Health and the Environment

This remedial alternative achieves the RAOs through removal of impacted soil in the potential exposure depth interval and replacement with unimpacted imported fill.

5.2.4.2 Compliance with ARARs

Removal of impacted soil from the remedial action areas delineated on Figure 4-11 to an off-site disposal facility would require compliance with ARARs related to dust emissions, stormwater controls, and disposal. Appropriate stormwater and air-quality controls would be used to protect air and water quality. Equipment leaving the work site would be decontaminated as needed to prevent tracking impacted soil on public roads, and each load of soil would be tracked to confirm that the material was received by the designated disposal facility.

5.2.4.3 Long-Term Effectiveness

The long-term effectiveness of this remedial alternative is primarily derived from the removal and secure disposal of soil in the 0- to 10-foot depth interval with $TEQ_{DF,M}$ concentrations exceeding the PRG. Approximately 50,000 cy of soil would be removed from the three remedial action areas south of I-10. The anticipated limits of the excavations are shown in Figure 4-11. The excavated areas would be restored to existing grade and vegetative cover would be re-established. As all of the soil in the affected depth interval (0- to 10-feet below grade) would be replaced with unimpacted, imported fill, the residual risk would be negligible.

5.2.4.4 Reduction of Toxicity, Mobility or Volume

This remedial alternative would involve no reduction of TMV through treatment. The soil may be landfilled without treatment of the COCs. Some of the soil may require dewatering to eliminate free liquids for transportation and disposal. Drying by amendment with Portland cement would incidentally reduce the potential mobility of COCs adsorbed to the soil.

5.2.4.5 Short-Term Effectiveness

Excavation of impacted soil would temporarily increase the potential for exposure to COCs. Dust suppression would be implemented during excavation and backfilling operations to control potential inhalation hazards. Stormwater controls would be implemented to minimize the potential for releasing impacted soil, although the potential exists for a release if an extreme storm or high-water event floods the Site while one of the excavations is open. The excavations should be backfilled as soon as practical to minimize the potential for such a release. Additional environmental risks include the possibility of spills during transportation to the disposal facility and possible releases from the off-site landfill itself. In addition to these environmental risks, as compared to the previous three remedial alternatives, the construction of this alternative would have higher greenhouse gas and PM impacts, and ozone generation emissions associated with construction emissions from equipment operating within the project work area, as well as from equipment required for transportation and disposal of excavated soil. However, there are other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the presence of I-10. This remedial alternative, like Alternatives 1S through 3S, would achieve full protection in the area south of I-10 immediately upon completion of construction.

5.2.4.6 Implementability

There are no significant implementability concerns associated with this remedial alternative. Excavated soil may be loaded directly into trucks for transportation to the disposal facility to eliminate the need for stockpiles of impacted soil. Dewatering (groundwater lowering) may be necessary to allow excavation to 10-feet below grade in sufficiently dry conditions, but excavation of soil to 10-feet is a standard construction operation that will not require specialized equipment or workers. Two landfills have been contacted that have indicated preliminarily that they would be able to accept the soil. The compliance status of the selected disposal facility would be confirmed, in conformance to the Off-site Rule, by communication with the USEPA Regional Off-Site Contact prior to beginning construction. The most significant implementability concern may be the temporary additional truck traffic on Market Street and access roads to I-10. Provisions may need to be made to time this traffic or to accommodate the increased volume.

5.2.4.7 Cost

The estimated present worth cost associated with this remedial alternative is $9.9 million (Appendix C). The capital costs for this remedial alternative are primarily associated with the excavation and disposal of soil and conducting USEPA 5-year reviews.

6 COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section compares the alternatives relative to each of the FS evaluation criteria listed under the NCP. Tables 5-1 and 5-2 summarize the criteria for each alternative and provide the basis for the comparative evaluation discussion in this section. Table 6-1 provides an evaluation summary for all of the criteria, assessed using the criteria "Low," "Medium" and "High", where "Low" represents the least favorable, and "High" represents the most favorable assessment of the alternative relative to the specific criterion.

6.1 Area North of I-10

6.1.1 Threshold Criteria

All of the remedial alternatives evaluated in this FS for the area north of I-10 satisfy the threshold criteria of protecting human health and the environment and addressing ARARs. As noted in the RAM, the surface-weighted average $TEQ_{DF,M}$ concentration in surface sediments (which are associated with a variety of dioxin sources in addition to paper mill waste that was placed in the impoundments) was reduced by more than 80 percent by the implementation of the TCRA. Based on the fate and transport modeling, this reduction in sediment concentration translates to improvements in water quality throughout the USEPA's Preliminary Site Perimeter (see Table 3-2 in Appendix A), even though there are ongoing inputs of dioxins and furans from sources other than the impoundments, as discussed previously. The current (post-TCRA) condition within the USEPA's Preliminary Site Perimeter is such that there is little potential for exposure to $TEQ_{DF,M}$ concentrations unless there is a future release due to an extreme storm or hurricane, or a future release due to the impacts of a barge strike.

6.1.2 Long-Term Effectiveness

The long-term effectiveness evaluation of MNR-based remedies (Appendix A) projects that the SWAC $TEQ_{DF,M}$ will decrease by approximately a factor of two in a 10- to 15-year time frame within the USEPA's Preliminary Site Perimeter (Appendix A) due to natural sedimentation processes in the river. Construction of the Armored Cap reduced SWAC $TEQ_{DF,M}$ within the USEPA's Preliminary Site Perimeter by approximately 80 percent, and natural recovery will continue to reduce SWAC $TEQ_{DF,M}$ because of the ongoing input of sediment with low $TEQ_{DF,M}$ concentrations from upstream sources.

Alternative 1N does not include ICs and MNR is not assessed over time, so the long-term effectiveness of this alternative ranks lower than all of the other alternatives. The existing

Armored Cap is not further enhanced in Alternatives 1N or 2N compared to Alternative 3N, which could increase the need for future long-term monitoring and maintenance under Alternatives 1N and 2N.

The evaluations performed to address the permanence of the existing repaired TCRA cap with the proposed modifications outlined in the capping Alternative 3N showed that the cap is expected to be stable and permanent, requiring only maintenance or repair following unusual catastrophic events. The expected losses from such events would be expected to be small, comparable or smaller than losses from removal of the contaminated sediment as predicted for dredging Alternative 6N. However, the uncertainty inherent in any quantitative analysis technique used to estimate the long-term (500 years) reliability of the cap is very high. This includes the empirical analysis developed by Maynord (2000) to estimate the potential scour of the cap due to prop wash generated by ship traffic since a lot of the site data needed to properly perform this analysis were not available. The latter analysis probably has the smallest uncertainty associated with any of the evaluations performed to assess the long term reliability of the cap, and its estimated uncertainty is at least ± one order of magnitude. So, if the estimate of prop induced scour is 10 cm, then than range of uncertainty would be from 1 cm to 100 cm. This estimate of the uncertainty takes into account the lack of a complete data set for the Site and the uncertainty in Maynord's empirically based methodology itself. Further, changes in channel planform morphology due to bank erosion, shoreline breaches, etc. during a high flow event caused by a major flood or hurricane as occurred in other areas of the San Jacinto River during the 1994 storm is beyond the ability of existing sediment transport models to simulate.

The impact of continued subsidence on the integrity and reliability of the existing cap to prevent any release of contaminated material would be dependent on the long-term rate of subsidence. The latter is not well known and cannot be predicted with any reliability. In general, subsidence and the slow rise in sea level would both result in slightly deeper water depths over the Eastern Cell and Northwestern Area of the cap, but it is not believed that these effects would be substantial enough to affect the tidal, river and wind induced circulation in the San Jacinto River estuary. As such, it is not believed that the reliability of the cap would be lessened.

Regarding the potential impacts of barge strikes, strikes pose significant impacts only from loaded barges and only in proximity of the Northwestern Area. Strikes on the present 1V:2H or the proposed upgraded 1V:3H slope could cause sloughing from gouging and displacement of armor and slope instability from grounding due to the added loadings on the slope from the grounded weight of the barge, exposing a sizeable area of highly contaminated sediment. Low to moderate impacts can occur in the same area from the grounding of an empty barge on the mildly sloped area above the steep slope. This would expose a relatively small area having high levels of contamination in the area immediately north of the Western Cell and directly north and east of the northern end of the center berm.

The impacts of strikes during high flow flood conditions are much greater due to potential erosion of exposed sediment; however, flood conditions occur only about 1%. Strike protection control measures, such as pilings, caissons or a wall, could be used in a 500 to 700 foot reach along the base of the slope in the deep water (15 feet) of the Northwest Area. These control measures could prevent all but very low impact strikes.

Alternatives 4N, 5N, 5aN, and 6N, which involve either S/S or partial or full removal, all result in increased long-term protectiveness compared to Alternatives 1N, 2N, and 3N because either the resistance to erosion or damage is increased (Alternative 4N), or the potential loss to erosion or damage is reduced due to the removal of part (Alternatives 5N and 5aN) or all (Alternative 6N) of the waste material. All of the alternatives that involve removal of part or all of the cap will result in releases during construction, however these releases would be mitigated by using BMPs including excavation in the dry where possible, berms, sheet piles, silt curtains, cap removal in sections, etc.

There will also be a requirement for a residuals management cover or backfill over the excavated areas for Alternatives 5N, 5aN, and 6N.

Based on the results of the modeling described in Appendix A, the Alternative 6N construction releases, which may be the most extensive of all the alternatives, are predicted to result in TCDD increases of 3 to 10 ng/kg over most of the USEPA's Preliminary Site Perimeter, with increases of over 30 ng/kg immediately adjacent to the waste pits. However, the use of BMPs as described above would reduce the impact of TCDD resuspension. For Alternative 1N, the no action alternative, the initial TCDD present over the USEPA's Preliminary Site Perimeter is approximately 8 ng/kg. Therefore, the total TCDD present following construction of Alternative 6N would be 18 ng/kg (8 ng/kg initial plus 10 ng/kg increase) over the USEPA's Preliminary Site Perimeter, but well below the PRG of 200 ng/kg. The model-predicted decline of TCDD in surface sediment concentrations within the USEPA's Preliminary Site Perimeter corresponds to a half-life of 11 years. Although the model results vary year-to-year due to differences in flow conditions (which drive differences in sediment transport), the nature of the predicted recovery curve (i.e., an exponential decline) exhibits an asymptotic behavior, which is expected because concentrations of dioxins/furans would be expected to approach regional background concentrations associated with remaining sources of dioxins/furans (i.e., point and non-point sources, transport from upstream, etc.) in the area. Alternative 6N has the greatest long-term effectiveness and protectiveness of all the alternatives because all of the waste material would be removed and not subject to the potentially severe conditions in the San Jacinto River, and because any construction related releases would result in sediment concentrations initially well below the PRG with further sediment concentration declines over the long term..

Figures 6-1a and 6-1b compare model-predicted surface sediment TCDD[6] concentrations at the end of the long-term fate model simulation for all of the alternatives. Results were averaged over the USEPA's Preliminary Site Perimeter and within the TCRA Site (Figure 6-1a), and by river mile in the vicinity of the TCRA Site (Figure 6-1b).

The long-term impacts of dredge residuals and releases during construction are also evident in the model-predicted water column concentrations at the end of the long-term simulation (see Figure 6-2, which shows model-predicted annual average water column TCDD concentrations at the end of the long-term model simulation for all of the alternatives, averaged over the USEPA's Preliminary Site Perimeter and the TCRA Site. However, the actual impact of dredge residuals will be reduced by the use of BMPs, including using a two layer residuals cover system. These predictions include several sources of dioxins and furans, including atmospheric deposition, upstream sources, and point sources, such as releases from wastewater treatment plant outfalls, in addition to the dioxin-impacted materials potentially released during dredging and S/S activities.

6.1.3 Reduction of Toxicity, Mobility or Volume

Alternatives 1N and 2N do not include additional measures to reduce TMV. However, a portion of the soils in the Western Cell were previously solidified during the TCRA as shown in Figures 4-1, 4-3, 4-5, 4-7, and 4-9. Thus, these alternatives are comparable in reduction of TMV. Alternative 3N further reduces potential mobility within the TCRA Site by increasing the protection of the armored slopes, and thus ranks more favorably than Alternatives 1N and 2N. Alternatives 4N and 5N take additional measures through S/S (Alternative 4N) or removal (Alternative 5N) of approximately 52,000 cy of sediments and soils, and are comparatively better than Alternative 3N for reduction of TMV. Potential mobility of the highest concentration materials addressed in Alternatives 4N and 5N would be increased during remedy implementation, somewhat offsetting any reduction in TMV. Alternative 5aN removes approximately 137,600 cy of sediment, and thus compares more favorably for reduction of TMV than Alternatives 4N and 5N, but subject again to possible issues related to mobility of materials during remedy implementation. Alternative 6N has the greatest volume of removal – 200,100 cy. This alternative is more effective in reducing the toxicity, mobility, and volume of waste compared all of the other alternatives.

---

[6] Although the FS focuses on SWAC $TEQ_{DF,M}$ as a metric of sediment quality, the TCDD results from Appendix A provide a reasonable surrogate for $TEQ_{DF,M}$ because TCDD represents the majority of the potential risk in the calculation of $TEQ_{DF,M}$.

6.1.4 Short-Term Effectiveness

Alternatives 1N and 2N do not entail any construction, and thus have no short-term impacts. Alternative 3N has the shortest duration of the remaining alternatives, does not result in water column, sediment, or tissue impacts (except for minor turbidity during armor rock placement), and has the lowest risk to worker safety, the lowest greenhouse gas and PM emissions, and the least traffic and ozone (smog) impact. Further, Alternative 3N does not disturb the Armored Cap or require handling of sediments. Compared to Alternatives 4N, 5N, 5aN, and 6N, which have longer durations, Alternative 3N ranks more favorably for short-term effectiveness.

Alternatives 4N, 5N, 5aN, and 6N each have risk of short-term impacts associated with residuals and releases during construction. Because of their longer duration these alternatives also have a higher likelihood that a high-water event during construction could overtop perimeter water quality control features, which would exacerbate short-term impacts because the Armor Cap needs to be removed to accomplish the work. Figure 6-3 provides a comparison of the model-generated average Year 1 water column concentrations of TCDD for all alternatives, for both the USEPA Preliminary Site Perimeter, as well as for the TCRA Site, as predicted by the model. As shown in this figure, Alternatives 4N, 5N, 5aN, and 6N have a model-predicted increase in water column TCDD concentrations averaged over USEPA's Preliminary Site Perimeter of five-fold, twenty-fold, thirty-fold, and one hundred-fold, respectively, over alternatives 1N, 2N, and 3N. However, the actual levels would be reduced by the use of BMPs during construction.

Alternative 4N has a longer construction duration than Alternatives 5N and 6N and all entail removing portions of the Armored Cap and managing a volume of sediments. Compared to Alternative 3N, there is higher risk to worker safety (8 to 9 times the number of injuries and fatalities, Table 4-5) and higher environmental impacts (8 to 9 times the number of hours of operation and truck trips, Table 4-4) due to releases that would be expected during construction. Alternative 4N is considered similar to Alternative 5N for emissions of ozone precursors, PM (smog-forming) and greenhouse gases; under Alternative 4N, construction is limited to work within the USEPA's Preliminary Site Perimeter and does not result in additional emissions during off-site shipment of sediments, but this is counterbalanced by the shorter duration of Alternative 5N.

Alternative 5aN has the longest construction duration. Alternatives 5aN and 6N are the least favorable for short-term effectiveness. The greater number of work hours has attendant higher worker safety risk (20 times the number of injuries and fatalities compared to Alternative 3N, Table 4-5) and higher emissions of ozone precursors, PM (smog-forming) and greenhouse gases (20 times the number of equipment operating hours and truck trips compared to Alternative 3N, Table 4-4), and the time required for Alternatives 5aN and 6N to achieve protection is also longer. Alternative 6N also has the most short-term environmental impact due to model-generated water column releases during dredging, and the expected localized increase in tissue concentrations from these releases, as well as generated dredge residuals, that the model predicts may increase the overall SWAC $TEQ_{DF,M}$ immediately following dredging. However, the actual levels would be reduced by the use of BMPs during construction, including excavation in the dry, etc..

6.1.5 Implementability

Alternatives 1N and 2N do not have any implementability issues because they do not entail construction. Both are more favorable from an implementability standpoint compared to Alternatives 3N, 4N, 5N, 5aN, and 6N. Alternative 3N is a short-duration project that entails proven technology (i.e., the same activities were demonstrated during construction of the Armored Cap) that can be deployed with readily-available materials and local, experienced contractors.

Implementability concerns, such as TCRA Site access, limited staging areas, restrictions on equipment size, and availability of off-site staging area properties are greater for Alternatives 4N, 5N, 5aN, and 6N compared to Alternative 3N because of the much larger scope and scale of these alternatives. Identifying and securing an off-site staging area is considered an even greater challenge for Alternatives 5N, 5aN, and 6N compared to Alternative 4N because dredged sediment would need to be managed at the off-site staging area, which requires a larger footprint, and given the nature of the dredged material, might make finding a willing landowner difficult. Proper management of cap material and excavated wastes, and on-site processing and management for dredged sediments for off-site transportation to neighboring roadways, will be critical for effective implementation of Alternatives 5N, 5aN, and 6N. Finding a suitable off-site facility for Alternatives 5N, 5aN, and 6N is considered a more significant implementability challenge than Alternative 4N because the former alternatives will manage dredged sediments at the facility. Compared to Alternative 5N, this issue is magnified for Alternatives 5aN and 6N because of the greater volume of material that must be handled at the off-site facility. Based on these factors, Alternative 3N is less favorable than Alternatives 1N and 2N, but more favorable than the remaining alternatives.

Alternative 4N requires the removal of the Armored Cap, and requires S/S to be completed for an area of sediments that is typically submerged and would need to be dewatered, which is considered a technical challenge. Engineering controls for Alternative 4N may not be adequate to prevent the release of sediments exceeding PRGs to the surrounding environment; this would be especially true during potential high flow events that could occur during construction. Alternative 4N is considered to be less favorable for implementability compared to Alternative 3N.

Alternatives 5N, 5aN, and 6N also require removal of the Armored Cap and management of sediment and soil for off-site disposal. Similar to Alternative 4N, engineering controls may not be adequate to prevent the release of sediments exceeding PRGs to the surrounding environment. For Alternatives 4N through 6N there is a 30 to 40 percent chance that a high water event could occur during construction resulting in overtopping of the engineering controls. Thus, all of these alternatives are considered equally less favorable as Alternative 4N for implementability compared to Alternatives 1N, 2N, and 3N.

6.1.6 Cost

Table 5-1 includes a summary of estimated costs for each alternative. Appendix C provides the detailed estimates that were developed for this FS Report. Costs range from lowest to highest in order from Alternative 1N to Alternative 6N: Alternative 1N is estimated to cost \$9.5 million; Alternative 2N is estimated to cost \$10.3 million; Alternatives 3N and 4N differ by a factor of almost 2, with estimated costs of \$12.5 and \$23.2 million, respectively; Alternative 5N is estimated to cost \$38.1 million; Alternative 5aN is estimated to cost \$77.9 million; Alternative 6N is estimated to cost \$99.2 million. Estimated costs include development and operation of the off-site staging area. However, because the exact location and configuration of the off-site staging area are beyond the scope of this FS these elements may not be fully reflected in the FS estimated durations or costs.

6.1.7 Summary of Comparative Benefits and Risks

The comparative benefits of each alternative have been assessed using the modeling described in Appendix A to predict the TCDD sediment and water column concentrations within the USEPA's Preliminary Site Perimeter at the end of construction, and at the end of the long-term simulation period. As discussed, these reductions follow the already-achieved reductions that occurred following completion of the TCRA. As is shown in Figures 6-1a, 6-1b, 6-2, and 6-3, removal and S/S-based alternatives 4N, 5N, 5aN, and 6N have potential short-term impacts due to releases during construction; in contrast, Alternatives 1N, 2N, and 3N do not have similar impacts to sediments and water column concentrations. Alternative 4N would increase the shear strength of soils and sediments through treatment, which would further increase their stability beyond that provided by the Armored Cap. Alternatives 5N, 5aN, and 6N would remove impacted sediments from the Site and thus provide higher long-term protectiveness. Alternative 3N relies on the Permanent Cap, but retains the capped material at the Site that would result in the potential for a future release due to an extreme storm or hurricane or the impacts of a barge strike. Alternatives 1N and 2N do not enhance the existing Armored Cap, and so provide lower long-term protectiveness than all of the other alternatives.

Additionally there is risk of harm to the environment during implementation of the remedies associated with Alternatives 4N, 5N, 5aN, and 6N, although these risks would be mitigated by the use of BMPs and engineering controls as discussed under Short-Term Effectiveness. Risks from short-term environmental impacts during and following construction (water column, sediment, and localized tissue impacts) and worker safety (estimated injury and fatality rates) are significantly (7 to 20 times; Table 4-4 and Table 4-5) higher for Alternatives 4N, 5N, 5aN, and 6N than for Alternatives 1N, 2N, or 3N.

Alternatives 4N, 5N, 5aN, and 6N are less sustainable alternatives, as assessed, considering potential ozone precursor, PM and greenhouse gas emissions from the construction activity, and will result in more community impact from traffic including on-going daily distractions and the potential for accidents and off-site spills (6 to nearly 70 times the number of truck trips; Table 4-4). However, incremental community impact of traffic will be affected by the other sources of air emissions and traffic in the region, including the industrial activities that occur adjacent to the Site and the nearby presence of I-10. These alternatives are expected to require a relatively large off-site facility for management of materials and related activities (armor rock and dredged sediment stockpiling, sediment dewatering, transloading, and off-site shipping), which could be difficult to obtain.

6.2 Area South of I-10

Other than Alternative 1S, the remedial alternatives for the area south of I-10 considered in this FS Report meet both of the threshold criteria: protectiveness and compliance with ARARs. The potentially affected receptor (hypothetical future construction worker) would be protected from exposure to soil with elevated $TEQ_{DF,M}$ concentrations by warnings and restrictions (Alternatives 2S and 3S) or removal of impacted soil (Alternative 4S).

The pockets of subsurface soil with $TEQ_{DF, M}$ concentrations exceeding the hypothetical future construction worker PRG in the area south of I-10 are isolated from the surface by several feet of clean soil. $TEQ_{DF, M}$ concentrations for specific sample intervals are shown in Figure 2-5. Potential exposure to soil exceeding the PRG in this area is limited to circumstances involving excavation into the affected depth zone or potential contact with excavated soil if it were to be left at the surface. The hypothetical future construction worker PRG is based on exposure to soil from 0- to 10-feet below the surface. Average $TEQ_{DF,M}$ concentrations in the 0- to 10-foot interval are shown in Figure 3-5.

With reasonable care, any of the remedial alternatives could be implemented in compliance with ARARs. Soil that is removed (Alternative 4S) would be transported in compliance with Department of Transportation standards and permanently managed in a permitted landfill cleared by the USEPA's regional off-site rule contact. BMPs would be implemented to control dust, stormwater, and potential releases of impacted soil.

6.2.1 Long-Term Effectiveness

As noted in the previous section, soil with $TEQ_{DF,M}$ concentrations exceeding the PRG is isolated from the surface by clean overburden. The only route of potential exposure is through excavation into the impacted depth interval. Through the use of appropriate PPE and proper management of excavated soil, the potential risks posed by the impacted soil can be reliably and effectively managed. The physical markers (Alternative 3S) would draw attention to the ICs and enhance their effectiveness. Alternative 4S would achieve long-term effectiveness by permanently removing the impacted soil from the 0- to 10-foot depth interval from the Site and securely disposing of the soil in a permitted landfill. While the ICs, particularly with the addition of physical markers (Alternative 3S), would provide reliable long-term protection, they rely on the integrity of future construction workers to comply with the restrictions. Therefore, complete removal of the impacted soil in the depth interval of potential excavation (Alternative 4S) may provide a somewhat higher level of long-term effectiveness because it is not subject to inappropriate future use of the area.

6.2.2 Reduction of Toxicity, Mobility and Volume

Alternatives 2S and 3S do not include any treatment of impacted soil. Alternative 4S would include some treatment of excavated soil, as needed to eliminate free liquids for transportation and disposal. The treatment may involve amendment of the soil with Portland cement, which would reduce the potential mobility of COCs. Water removed from the excavation would be treated, if necessary, to reduce toxicity prior to discharge.

6.2.3 Short-Term Effectiveness

Alternative 2S does not entail any construction, and thus has no short-term impacts. Excavations (Alternative 3S and 4S) would require BMPs to control dust and stormwater. Short-term impacts associated with Alternative 3S would be minimal given the shallow depth of excavation, limited volume of material that would be moved, and absence of significant concentrations of COCs in the shallow soil. Alternative 4S would require exposing soil with $TEQ_{DF,M}$ concentrations exceeding the PRG, which introduces the potential for exposure to COCs through direct contact with the soil, inhalation or ingestion of impacted dust, and contact with impacted soil suspended in runoff. The volume of soil and the duration of the project would also be greater than for Alternative 3S, and Alternative 4S would require off-site transportation of the soil to a disposal facility, increasing the potential for exposure to COCs, emissions of greenhouse gasses, nitrogen oxides (NOx), and PM, and potential tracking of COCs off-site. However, measures would be implemented to reduce the amount of any materials lost during transportation.

6.2.4 Implementability

There are no significant implementability concerns associated with Alternatives 2S and 3S. None of the alternatives requires specialized equipment, techniques, or personnel. Coordination with property owners would be required to establish ICs and for access to the project work site. Alternative 4S would involve more physical activity for implementation, including off-site transportation of impacted soil, but the operations are routine for remedial actions. The additional implementability concerns are the increased truck traffic on Market Street and the potential for flooding while impacted soil is exposed during implementation of Alternative 4S. Provisions may need to be made to handle the additional volume of traffic. The duration of the excavation should not exceed 7 months and implementation could be timed for periods when high water is least likely.

6.2.5 Cost

Table 5-1 includes a summary of estimated costs for each alternative. Appendix C provides the detailed estimates that were developed for this FS. Costs range from lowest to highest in order from Alternative 1S to Alternative 4S. Alternative 1S (No Action) is estimated to cost $140,000, Alternative 2S (ICs) is estimated to cost $270,000, Alternative 3S (Enhanced ICs) is estimated to cost $660,000, and Alternative 4S is estimated to cost $9.9 million.

6.2.6 Summary of Comparative Benefits and Risks

Alternative 4S would result in the permanent removal of impacted soil from the 0- to 10-foot interval. Risk management achieved by ICs is somewhat less for the area south of I-10, particularly with the addition of the physical markers that are part of Alternative 3S. Alternatives 2S and 3S would not require exposing impacted soil or transporting material off-site and would be simpler to implement. Excavation of impacted soil (Alternative 4S) would introduce short-term risks of exposure to COCs on-site and potentially off-site in the event of a release in route to the disposal facility. The cost of Alternative 4S, $9.9 million, is 15 times the cost of Alternative 3S and more than 35 times the cost of Alternative 2S. However, Alternatives 2S and 3S do not address the Principal Threat Waste, which Alternative 4S does by removal and disposal. Also, Alternative 4S offers increased long-term effectiveness by removing the impacted soil, although at an increased cost.

7 REFERENCES

Anchor Environmental, 2005. Public Review Draft Engineering Analysis/Cost Evaluation, Removal Action NW Natural "Gasco" Site. Prepared for submittal to the USEPA, Region 10. May 2005.

Anchor Environmental and Windward Environmental, 2005. East Waterway Operable Unit Phase 1 Removal Action Completion Report. Prepared for Port of Seattle for submittal to U.S. EPA Region 10. September 30, 2005.

Anchor QEA, 2009. Completion Report Berths 2 and 3 Interim Action Cleanup. Prepared for Port of Olympia. June 2009.

Anchor QEA and Arcadis, 2010. Phase 1 Evaluation Report: Hudson River PCBs Superfund Site. Prepared for General Electric Company. March 2010.

Anchor QEA and Integral, 2010a. Final Remedial Investigation/Feasibility Study Work Plan, San Jacinto Waste Pits Superfund Site. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company. November 2010.

Anchor QEA and Integral 2013. Groundwater SAP Addendum 2. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of International Paper Company. April 2013.

Anchor QEA, 2010. Draft Clean Water Act Section 404(B)(1) Evaluation, San Jacinto River Waste Pits Superfund Site. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company. December 2010.

Anchor QEA, 2011. Final Removal Action Work Plan, Time Critical Removal Action, San Jacinto River Waste Pits Superfund Site. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company. November 2010. Revised February 2011.

Anchor QEA, 2012a. Revised Draft Final Removal Action Completion Report, San Jacinto River Waste Pits Superfund Site. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company. Revised March 2012.

Anchor QEA, 2012b. Remedial Alternatives Memorandum San Jacinto River Waste Pits Superfund Site. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company. December 2012.

Anchor QEA, 2012c. Chemical Fate and Transport Modeling Report, San Jacinto Waste Pits Superfund Site. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company. October 2012.

Anchor QEA, 2012d. San Jacinto River Waste Pits TCRA Maintenance Completion Report. Prepared by Anchor QEA. Submitted to USEPA on August 27, 2012.

Anchor QEA, 2013. Letter to Gary Miller, USEPA Region 6. Regarding: San Jacinto River Waste Pits Superfund Site, Unilateral Administrative Order (UAO), Docket No. 06-03-10, November 20, 2009, Waste Classification Issue. May 14, 2013.

Anchor QEA, 2013a. San Jacinto River Waste Pits Time Critical Removal Action Report on Reassessment of Design and Construction. Prepared for U.S. Environmental Protection Agency Region 6 on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company by Anchor QEA, LLC. April 2013.

Anchor QEA, 2013b. Post-TCRA Quarterly Inspection Report - January 2013 Inspection.

Anchor QEA, 2014. San Jacinto River Waste Pits TCRA Armored Cap Enhancement Completion Report. Prepared for USEPA Region 6 by Anchor QEA, LLC. Dated February 21, 2014.

Anchor QEA, 2015. Letter to Gary Miller, USEPA Region 6. Regarding: San Jacinto River Waste Pits Superfund Site, Unilateral Administrative Order (UAO), Docket No. 06-03-10, November 20, 2009, Follow up to December 16, 2014 Meeting Re: Relative Bioavailability Adjustment.

Bridges et al., 2010. Dredging Processes and Remedy Effectiveness: Relationship to the 4 Rs of Environmental Dredging. Todd S. Bridges, Karl E. Gustavson, Paul Schroeder, Stephen J. Ells, Donald Hayes, Steven C. Nadeau, Michael R. Palermo, Clay Patmont. Integrated Environmental Assessment and Management. 2010 SETAC. February 10, 2010.

Dow, 2009. Reach D IRA Completion and Summary Report. Dow Chemical Co. November 16, 2009.

Ecology, 1995. Elliott Bay Waterfront Recontamination Study, Volumes I & II. Prepared for the Elliott Bay/Duwamish Restoration Program Panel. Panel Publication 10. Ecology Publication #95-607.

Federal Register, 1990. Preamble to the National Contingency Plan. 55 Federal Register 8666, at 8728. March 3, 1990.

Francingues and Palermo, 2005. "Silt Curtains as a Dredging Project Management Practice," DOER Technical Notes Collection (ERDC TN-DOER-E21). U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Renholds, 1998. In Situ Treatment of Contaminated Sediments. Prepared for U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response. Jon Renholds. December 1998. http://clu-in.org/products/intern/renhold.htm

Gardiner, J., B. Azzato, and M. Jacobi (Editors), 2008. Coastal and Estuarine Hazardous Waste Site Reports, September 2008. Seattle: Assessment and Restoration Division, Office Response and Restoration, National Oceanic and Atmospheric Administration. 148 pp.

GW Services, 1997. Workplan for Site Assessment of Portions of A, B, and C Yards, Southwest Shipyard Channelview, Texas. Groundwater Services, Inc., Houston, Texas. October 27, 1997.

Hart Crowser, 2003. Final Removal Action Completion Report Olympic View Resource Area Non-Time-Critical Removal Action Tacoma, Washington. Prepared for City of Tacoma by Hart Crowser and Pentec Environmental. March 28, 2003.

Hart Crowser, 2007. Draft Construction Completion Report Port Gamble Interim Remedial Action Woodwaste Removal Project. Port Gamble, Washington. Prepared for DNR. July 26, 2007.

HDR, 2013. Data Report Lower Duwamish Waterway, East Waterway, and West Waterway Subsurface Sediment Characterization Seattle, Washington. Prepared for US Army Corps of Engineers Seattle District by HDR Engineering Inc., Science and Engineering for the Environment, LLC, and Ken Taylor Associates. May 17, 2013.

Integral, 2010. Technical Memorandum on Bioaccumulation Modeling, San Jacinto River Waste Pits Superfund Site. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company. September 2010.

Integral, 2011. Chemicals of Potential Concern Memorandum. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company. May 2011.

Integral, 2013a. Baseline Ecological Risk Assessment. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company. May 2013.

Integral, 2013b. Baseline Human Health Risk Assessment, San Jacinto River Waste Pits Superfund Site. Prepared for McGinnes Industrial Maintenance Corporation, International Paper Company, and U.S. Environmental Protection Agency, Region 6. Integral Consulting, Inc., Seattle, WA. May 2013.

Integral and Anchor QEA, 2012. Preliminary Site Characterization Report, San Jacinto River Waste Pits Superfund Site. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company. February 2012.

Integral and Anchor QEA, 2013. Remedial Investigation Report. Prepared for U.S. Environmental Protection Agency, Region 6, on behalf of McGinnes Industrial Maintenance Corporation and International Paper Company. May 2013.

Khoury, 2016. E-mail to Carlos Sanchez. Diamond Alkali Phase I and SJRWP. March 2016.

Kita and Kubo, 1983. Proceedings of the 7th U.S./Japan Experts Meeting: Management of Bottom Sediments Containing Toxic Substances, 2-4 November 1981, New York City. U.S. Army Corps of Engineers, Water Resource Support Center.

Konechne, T., C. Patmont, and V. Magar, 2010. Tittabawassee River Cleanup Project Overview. USEPA/U.S. ACE/SMWG Joint Sediment Conference. April 2010.

Malcolm Pirnie and TAMS Consultants, 2004. Engineering Performance Standards Statement of the Engineering Performance Standards for Dredging. Prepared for U.S. Army Corps of Engineers, Kansas City District on behalf of U.S. Environmental Protection Agency, Region 2. April 2004.

Maynord, 2000

NOAA, 2010a. San Jacinto River Waste Pits. Updated: 2010. Available from: http://archive.orr.noaa.gov/book_shelf/1838_SanJacinto_River_Waste_Pits.pdf Accessed July 2013.

NOAA, 2010b. Federal Consistency Overview. Updated: March 10, 2010. Available from: http://coastalmanagement.noaa.gov/consistency/media/FC_overview_022009.pdf Accessed July 2013.

NRC, 2001. A Risk-Management Strategy for PCB-Contaminated Sediments. Committee on Remediation of PCB-Contaminated Sediments - Board on Environmental Studies and

Toxicology - Division on Life and Earth Studies. National Research Council, Washington, D.C. 2001.

NRC, 2007. Sediment Dredging at Superfund Megasites – Assessing the Effectiveness. National Research Council, Washington, DC: National Academy Press.

NTSB, 1996. National Transportation Safety Board. Evaluation of Pipeline Failures During Flooding and of Spill Response Actions, San Jacinto River Near Houston, Texas, October 1994. September 6, 1996.

OSHA, 2014. OSHA Fact Sheet Trenching and Excavation Safety. Found at: https://www.osha.gov/OshDoc/data_Hurricane_Facts/trench_excavation_fs.pdf

Patmont et al., 2013. Learning from the Past to Enhance Remedy Evaluation, Selection, and Implementation. C. Patmont, S. Nadeau and M. McCulloch. Presented at the Battelle International Conference on Remediation of Contaminated Sediments. February 2013.

Patmont, C., and M. Palermo, 2007. Case Studies of Environmental Dredging Residuals and Management Implications. Paper D-066, in: Remediation of Contaminated Sediments—2007, Proceedings of the Fourth International Conference on Remediation of Contaminated Sediments. Savannah, Georgia. January 2007.

Riddell, 2004. Overview of Laws Regarding the Navigation of Texas Streams. Compiled by Joe Riddell, Assistant Attorney General, Natural Resources Division, Office of Attorney General of Texas. January 2004. Found at: http://www.tpwd.state.tx.us/publications/nonpwdpubs/water_issues/rivers/navigation/riddell/index.phtml

Shaw et al., 2008. Lower Fox River Phase 1 Remedial Action Draft Summary Report 2007. Prepared for NCR Corporation and U.S. Paper Mills Corporation by Shaw Environmental and Infrastructure, Inc., Anchor Environmental, L.L.C., and Foth Infrastructure and Environment, L.L.C. February 21, 2008.

SMWG, 2008. Contaminated Sediments Database. Hosted by the Sediment Management Workgroup at: http://www.smwg.org/MCSS_Database/MCSS_Database_Docs.html

TCEQ and USEPA, 2006. Screening Site Assessment Report San Jacinto River Waste Pits, Channelview, Harris County, Texas. TXN000606611. Texas Commission on Environmental Quality and U.S. Environmental Protection Agency.

TCEQ and USEPA, 2008. HRS Documentation Record. San Jacinto River Waste Pits, Channelview, Harris County, Texas. TXN000606611. Texas Commission on Environmental Quality and U.S. Environmental Protection Agency. March, 2008

TCEQ, 2013. Houston-Galveston-Brazoria: Current Attainment Status. Texas Commission on Environmental Quality. http://www.tceq.texas.gov/airquality/sip/hgb/hgb-status

TDH, 1966. Investigation of Industrial Waste Disposal – Champion Paper, Inc. Pasadena. Texas State Department of Health Memorandum from Stanley W. Thompson, P.E., Regional Engineer, to the Director of the Division of Water Pollution Control. May 6, 1966.

Texas Parks and Wildlife Department (TPWD), 2009. 2009-2010 Texas Commercial Fishing Guide.

Texas State Historical Association (TSHA), 2009. The San Jacinto River. Texas State Historical Association. Accessed at: http://www.tshaonline.org/handbook/online/articles/SS/rns9.html. Accessed on December 25, 2009.

USACE, 1998. Guidance for Subaqueous Dredged Material Capping. Technical Report DOER-1. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. M.R. Palermo, J.E. Clausner, M.P. Rollings, G.L. Williams, T.E. Myers, T.J. Fredette, and R.E. Randall, 1998. Website: http://www.wes.army.mil/el/dots/doer/pdf/doer-1.pdf.

USACE, 2008a. The 4 Rs of Environmental Dredging: Resuspension, Release, Residuals, and Risk. ERDC/EL TR-08-4. U.S. Army Corps of Engineers. January, 2008.

USACE, 2008b. Technical Guidelines for Environmental Dredging of Contaminated Sediments. U.S. Army Corps of Engineers publication ERDC/EL TR-08-29. September 2008.

USACE, 2013. Review of Design, Construction and Repair of TCRA Armoring for the West Berm of San Jacinto Waste Pits. Prepared for USEPA, Region 6. USACE Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, Mississippi, 39180-6199. October 2013.

USDL, 2011. U.S. Department of Labor, Bureau of Labor Statistics. OSHA Recordable Case Rates and Census of Fatal Occupational Injuries. 2011.

Usenko, S., B. Brooks, E. Bruce, and S. Williams, 2009. Defining Biota-Sediment Accumulation Factors for the San Jacinto River Waste Pits, Texas Project Work Plan and QAQC Procedures. Center for Reservoir and Aquatic Systems Research and the Department of Environmental Science, Baylor University. September 2009.

USEPA, 1988 (OSWER Reference for RI/FS guidance). Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC.

USEPA, 1991. Risk Assessment Guidance for Superfund (RAGS): Volume 1 – Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals), Interim. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC. EPA/540/R-92/003.

USEPA, 1995. Determination of Background Concentrations of Inorganics in Soils and Sediments at Hazardous Waste Sites. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC. December 1995.

USEPA, 1997. Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments. EPA 540-R-97-006. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC.

USEPA, 1998. Assessment and Remediation of Contaminated Sediments (ARCS) Program. Guidance for In-Situ Subaqueous Capping of Contaminated Sediments. Michael Palermo, Steve Maynord, Jan Miller, Danny Reible. USEPA 905-B96-004. September 1998.

USEPA, 1999. Ecological Risk Assessment and Risk Management Principles for Superfund Sites, Final. OSWER Directive # 9285.7-28 P. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC.

USEPA, 2004. Dioxin Reassessment. National Academy of Sciences (NAS) Review draft. EPA/600/P-00/001Cb. U.S. Environmental Protection Agency, Washington, DC.

USEPA, 2004b. Second Five-Year Review Report for Commencement Bay Nearshore/Tideflat Superfund Site Tacoma, WA. U.S. Environmental Protection Agency Region 10. Dan Opalski. 2004.

USEPA, 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. Office of Solid Waste and Emergency Response (OSWER) 9355.0-85. December 2005.

USEPA, 2008. Wickes Park Saginaw River, Region 5 Cleanup Sites web site. Found at: http://www.epa.gov/region5/cleanup/dowchemical/wickespark/index.htm

USEPA, 2009a. Unilateral Administrative Order for Remedial Investigation/Feasibility Study. U.S. Environmental Protection Agency, Region 6, CERCLA Docket No. 06-03-10. In the matter of: San Jacinto River Waste Pits Superfund Site Pasadena, Texas. International Paper Company, Inc. & McGinnes Industrial Management Corporation, Respondents.

USEPA, 2009b. The National Study of Chemical Residues in Lake Fish Tissue. EPA-823-R-09-006. Office of Water, Office of Science and Technology. September 2009.

USEPA, 2009c. USEPA Region 6 Clean and Green Policy. September 1, 2009.

USEPA, 2009d. Remediation of the Black Lagoon Trenton, Michigan. Great Lakes Legacy Program. EPA-905-F0-9001. March 2009.

USEPA, 2009e. Kinnickinnic River Legacy Act Dredging Project Begins. USEPA Fact Sheet, June 2009.

USEPA, 2010a. Administrative Settlement Agreement and Order on Consent for Removal Action. U.S. EPA Region 6 CERCLA Docket No. 06-03-10. In the matter of: San Jacinto River Waste Pits Superfund Site Pasadena, Harris County, Texas. International Paper Company, Inc. & McGinnes Industrial Management Corporation,

USEPA, 2012a. Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites, OSWER Directive 9355.0-89. December 2012.

USEPA, 2012b. Letter to David Keith Anchor QEA, LLC. Regarding: Draft Final Remedial Alternatives Memorandum, San Jacinto River Waste Pits Superfund Site, Harris County, Texas, Unilateral Administrative Order CERCLA Docket No. 06-03-10. November 14, 2012.

USEPA, 2012c. Revised Final Removal Action Completion Report, San Jacinto River Waste Pits Superfund Site. May 2012.

USEPA, 2012d. Third Five-Year Review Report Wyckoff/Eagle Harbor Superfund Site Bainbridge Island, WA. U.S. Army Corps of Engineers, Seattle District. Prepared for U.S. Environmental Protection Agency Region 10 by Cami Grandinetti.

USGS, 1995. U.S. Department of the Interior, U.S. Geological Survey. Floods in Southeast Texas, October 1994, Fact Sheet. January 1995.

Van Siclen, D.C., 1991. Surficial Geology of the Houston Area: a Offlapping Series of Pleistocene (& Pliocene?) Highest-Sea Level Fluviodeltaic Sequences. Gulf Coast Assoc. Geol. Soc. Trans. 41: 651-666.